



NEW ZEALAND.

Department



of Mines.

GEOLOGICAL SURVEY BRANCH.

(P. G. MORGAN, Director).

BULLETIN No. 20 (NEW SERIES).

Map
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no. 20

THE GEOLOGY
OF THE
OAMARU DISTRICT,
NORTH OTAGO
(EASTERN OTAGO DIVISION).

BY

JAMES PARK, F.G.S.,

DEAN OF THE MINING FACULTY, OTAGO UNIVERSITY, DUNEDIN.

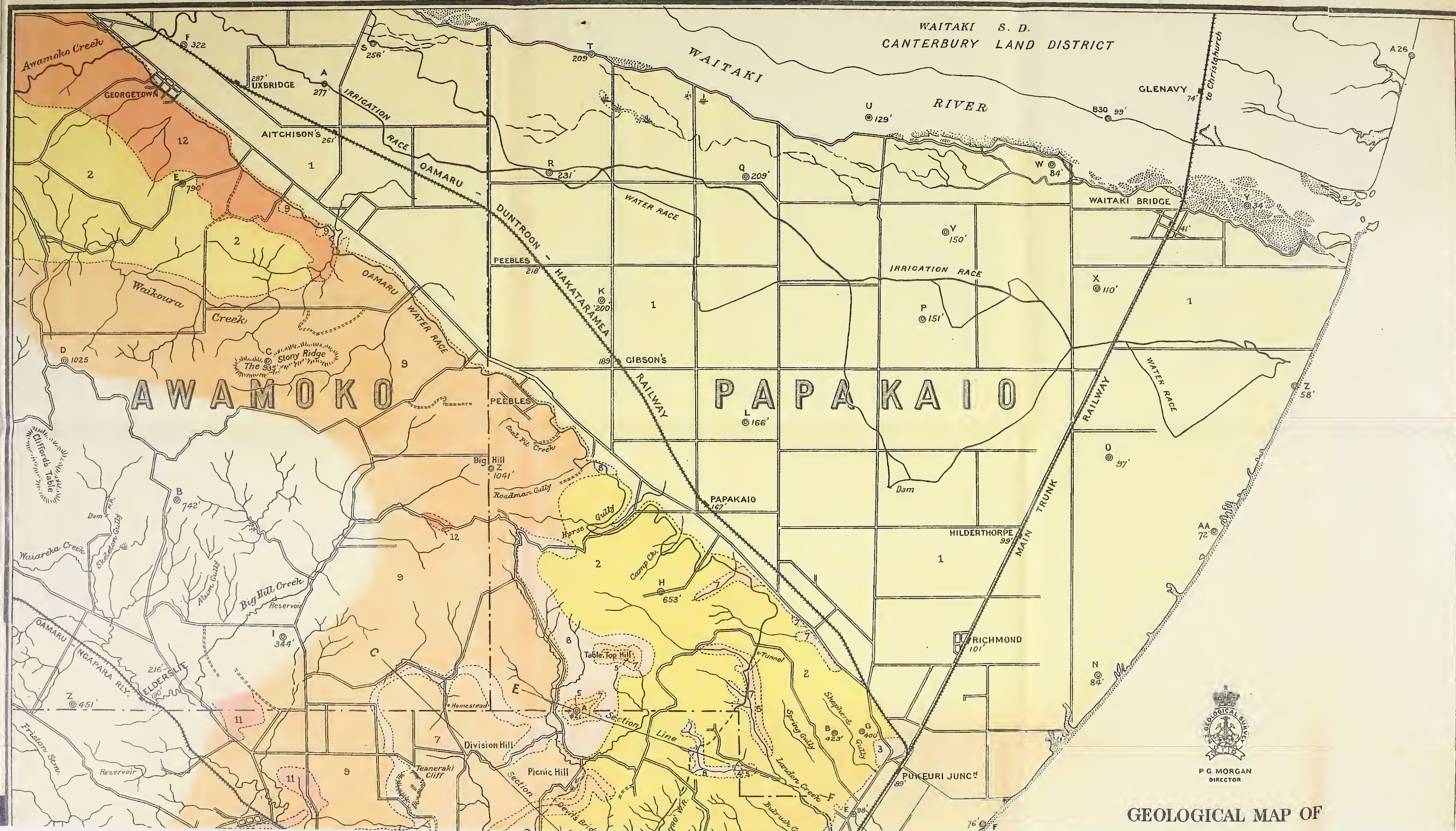
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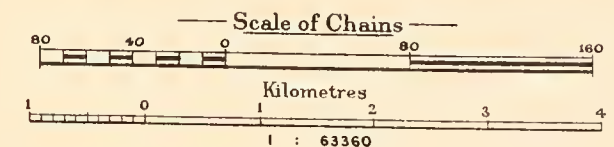
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1918.



GEOLOGICAL MAP OF PAPAKAIO AND PORTIONS OF AWAMOKO & OAMARU SURVEY DISTRICTS



Reference to Geological Colours

RECENT AND YOUNGER PLEISTOCENE	River gravels, forming river flats and low terraces	1	64'
OLDER PLEISTOCENE	High level gravels	2	
	Blue marine clays and sandy shell beds	3	AWAMOAN
	Greensands and glauconitic sandstones	4	HUTCHINSONIAN UPPER & LOWER
	Deborah (= Hutchinson Quarry) Limestone	5	
	Deborah (= Mineral) Tuffs	6	OTOTARAN
MIOCENE (OAMARUIAN)	Oamaru Stone	7	
	Waiareka tuffs and minor lava flows (pillow lavas)	8	WAIAREKAN
	Elderslie blue clays, micaceous sandstones, quartzose grits and conglomerates with lignite seam	9	NGAPARAN
	Basaltic flows and tuffs lying above Oamaru Stone	10	OTOTARAN
	Basaltic sills and dykes below Oamaru Stone	11	WAIAREKAN
PALÆOZOIC	Phyllites and Mica-schist	12	

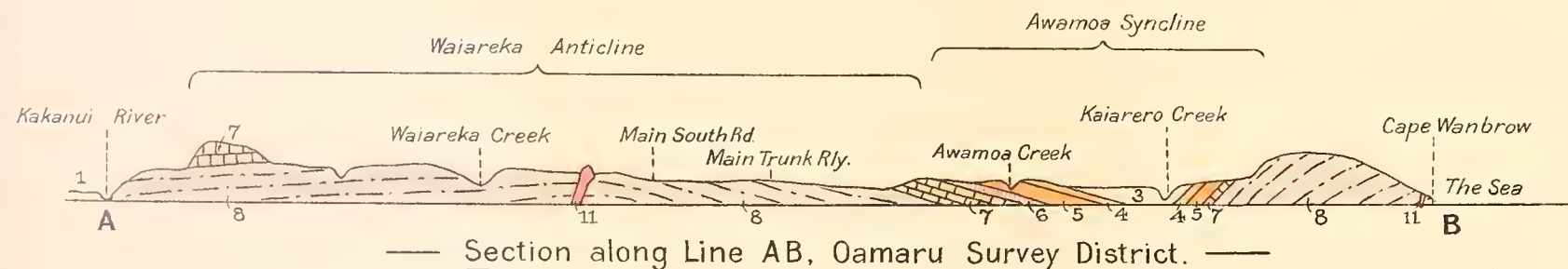
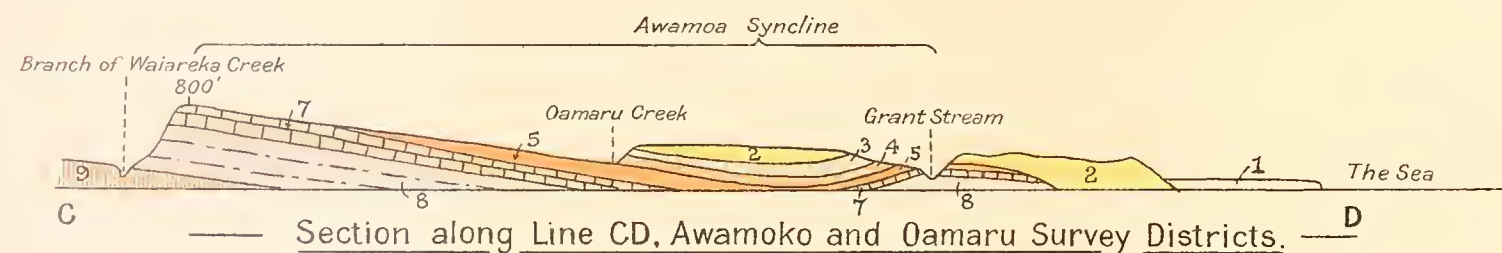
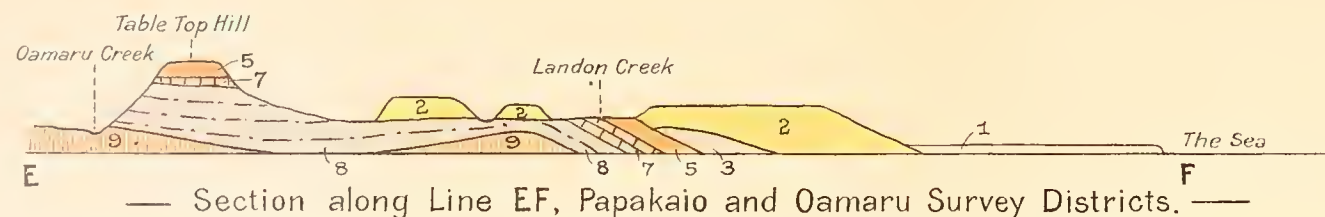
Reference

Roads	shown thus	
Tracks	"	
Trigonometrical Stations	"	C 184'
Swamp	"	
Water Races	"	
Railways	"	
Waterfalls and Dams	"	

Topography from Lands and Survey Dept. maps.
Geology by James Park.

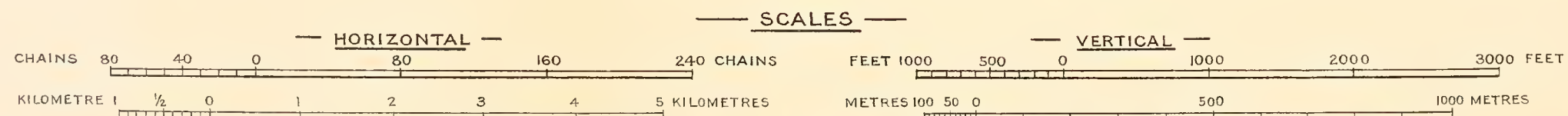


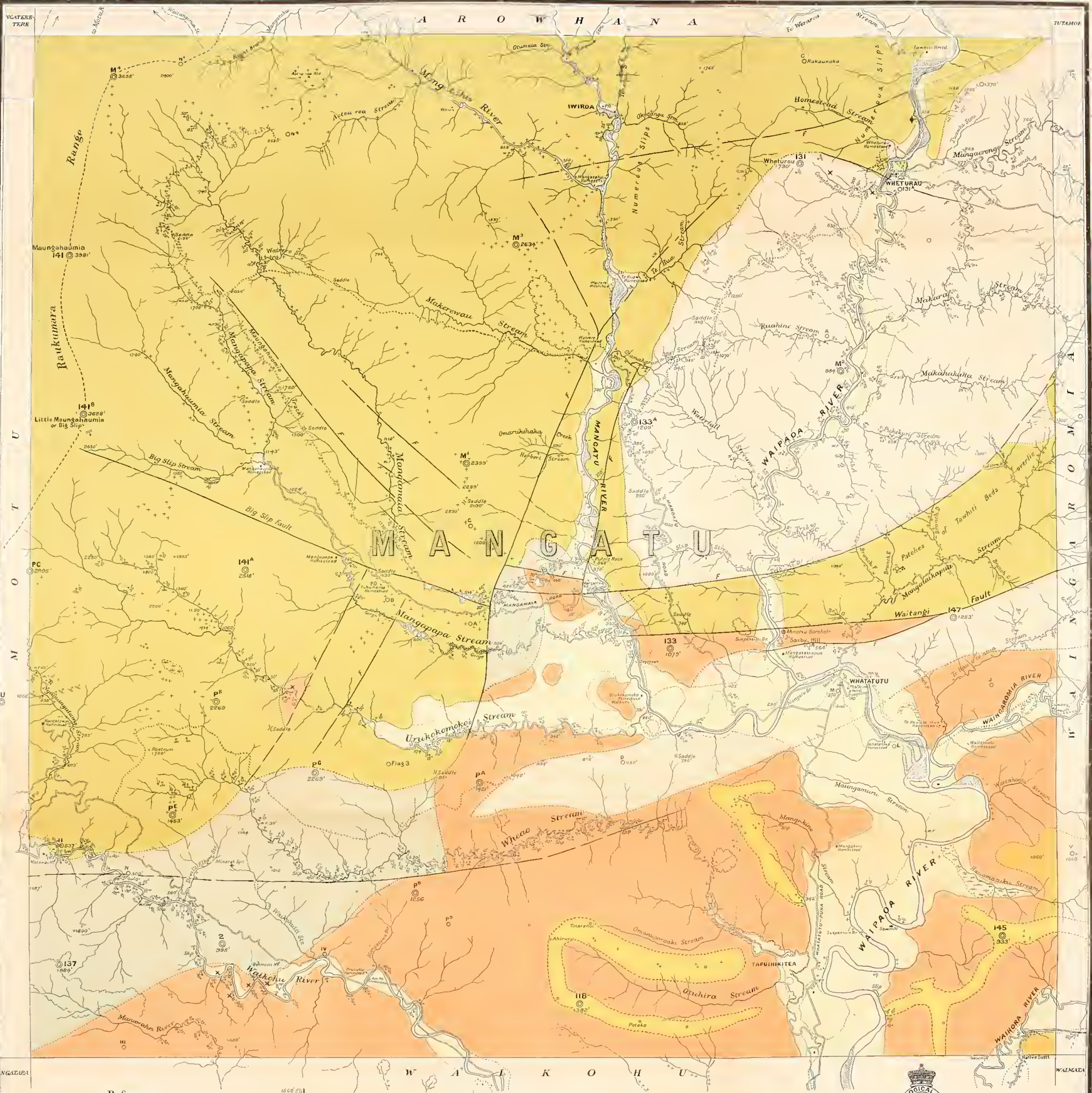
P. G. MORGAN
DIRECTOR.



— Reference to Geological Colours. —

MIOCENE (OAMARUIAN)	RECENT AND YOUNGER PLEISTOCENE	River gravels, forming river flats and low terraces.....	1
	OLDER PLEISTOCENE	High level gravels.....	2
	AWAMOAN	Blue marine clays and sandy shell beds.....	3
		Greensands and glauconitic sandstones.....	4
	HUTCHINSONIAN	Deborah (=Hutchinson's Quarry) Limestone.....	5
		Deborah (=Mineral) Tuffs.....	6
		Oamaru Stone.....	7
	OTOTARAN	Waiareka tuffs and minor lava flows. (pillow lavas).....	8
		{Elderslie blue clays, micaceous sandstones, quartzose grits and conglomerates with lignite seam..}	9
	WAIAREKAN		
	NGAPARAN		
		Basaltic sills and dykes below Oamaru Stone.....	11





GEOLOGICAL MAP OF MANGATUTU SURVEY DISTRICT



P. G. MORGAN.
DIRECTOR.

Compiled from data obtained from the Lands and Survey Department, and from additional surveys by J. H. Adams, J. Henderson, M. Ogley of the Geological Survey Branch of the Mines Department. Geology by J. H. Adams, J. Henderson, and M. Ogley.

- Reference
- Roads shown thus
 - Tracks
 - Trigonometrical Stations
 - Edges of Bush
 - Swamp
 - Water Races
 - Waterfalls and Dams
 - Springs
 - Boreholes

NOTE.—In order to exhibit the probable distribution of the older rocks, portions of Mr. J. H. Adams's areas of superficial rocks have been coloured to indicate the underlying rocks, but his boundaries are still shown by dotted lines.

RECENT AND LATE PLEISTOCENE	Fluvialite and estuarine gravels, sands and silts. Beach deposits and raised beaches. Aerial tuff.	
EARLY PLEISTOCENE	Waipaoa Series. Fluvialite, deltaic, and marine gravels, sands, and silts.	
	Unconformity.	
LOWER PLEISTOCENE	Ormond Series. Limestone, tuffaceous and calcareous sandstone, and	

UPPER MIOCENE	Tawhiti Series. Mudstone, argillaceous sandstone, and conglomerate.	
	Unconformity.	
LOWER MIOCENE	Te Arai Series. Mudstone, argillaceous sandstone, and conglomerate.	
	Unconformity.	

EOCENE (P)	Wheao Series. Shaly mudstone and sandstone.	
	Unconformity (P).	
CRETACEOUS	Mangatutu Series. Limestone, sandstone, greensandstone, and clay-shale.	

Outcrops with observed strike and dip.	1/40°
Outcrops with no observed strike and dip.	1/40°
Outcrops with vertical bedding.	#
Outcrops with horizontal bedding.	=
Quartz veins.	None.
Conglomerate bands.	X
Extinct Gas Vents.	+
Faults.	F

Compiled and drawn by R. J. Crawford, 1909. Additions by G. E. Harris, 1917.



GEOLOGICAL MAP OF PATUTAHU SURVEY DISTRICT

Reference

Roads — shown thus —
 Tracks — — — — —
 Trigonometrical Stations — — — — —
 Edges of Bush — — — — —
 Swamp — — — — —
 Water Races — — — — —
 Railways — — — — —
 Tram Lines — — — — —
 Waterfalls and Dams — — — — —
 Shafts and Drives — — — — —
 Springs — — — — —



— Reference to Geological Colours and Signs —

RECENT AND LATE PLEISTOCENE (Fluvial and estuarine gravels, sands and silts; Beach deposits and raised beaches. Aerial tuff.)
 Unconformity.

LOWER PLIOCENE (Ormond Series. Limestone, tuffaceous and calcareous sandstone, and mudstone.)
 Unconformity.

LOWER MIOCENE (Te Arai Series. Mudstone, argillaceous sandstone, and conglomerate.)

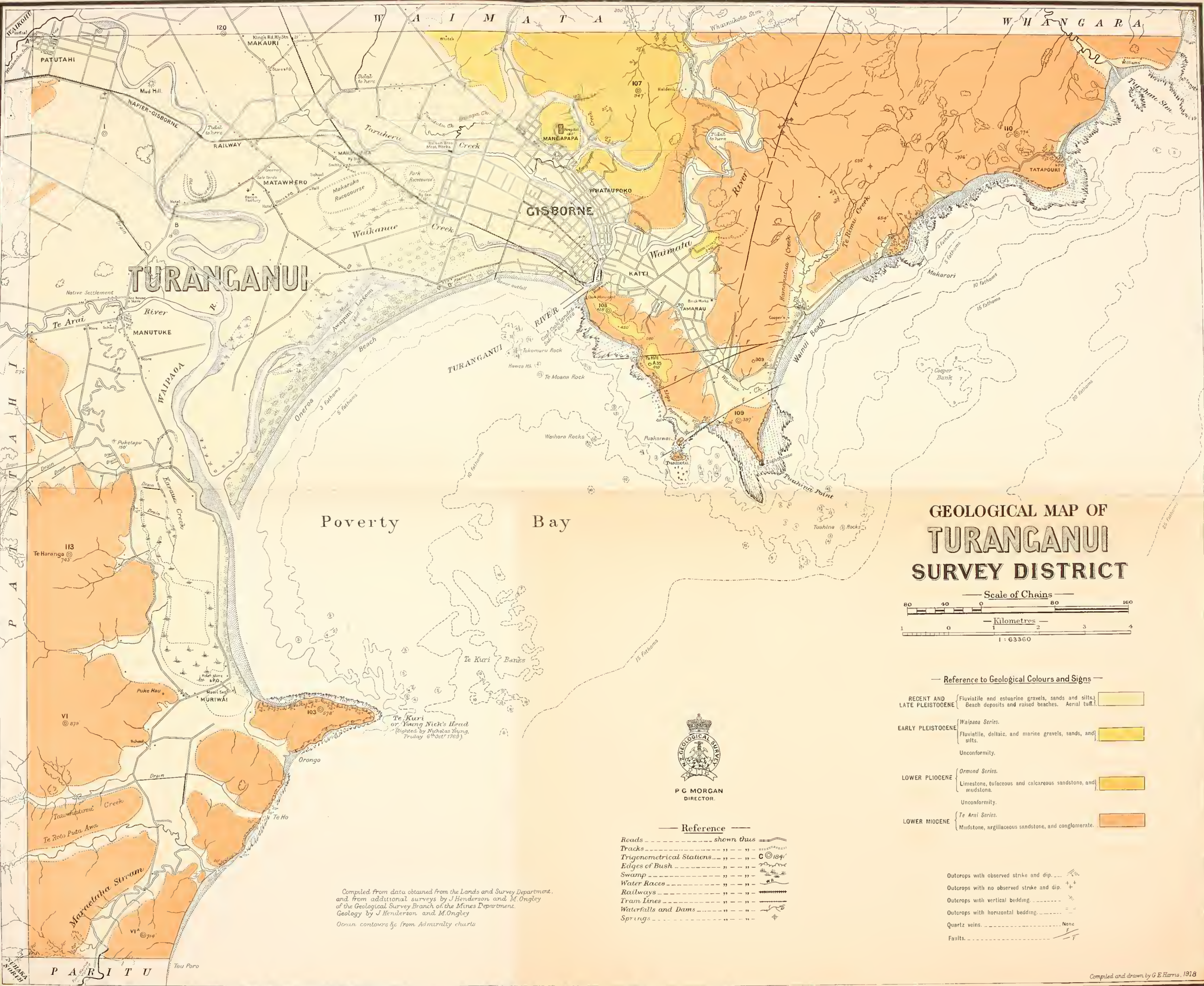
Outcrops with observed strike and dip. — — — — —
 Outcrops with no observed strike and dip. — — — — —
 Outcrops with vertical bedding. — — — — —
 Outcrops with horizontal bedding. — — — — —

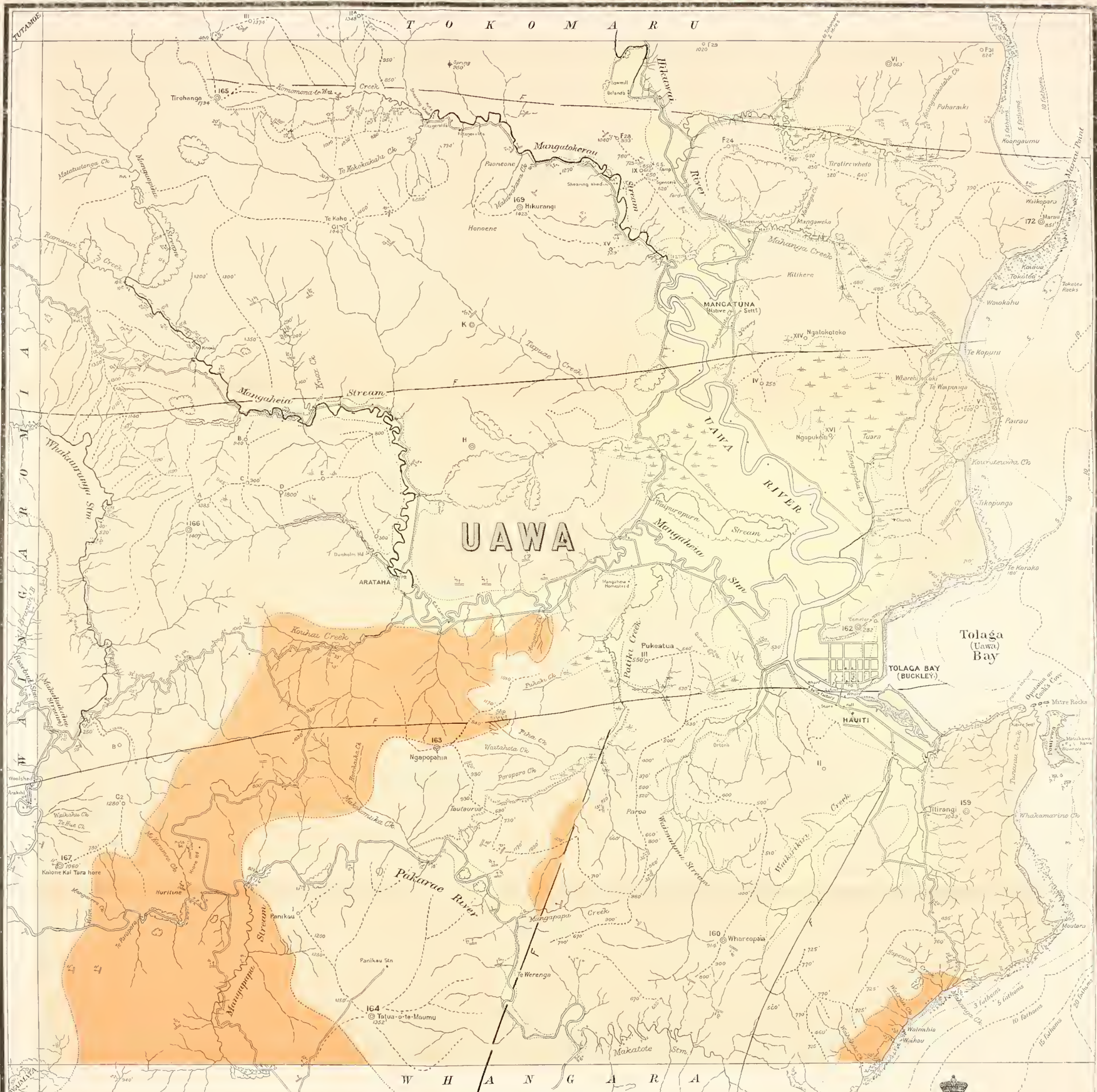
Quartz veins. — — — — —
 Extinct Gas Vents. — — — — —
 Faults. — — — — —



P. G. MORGAN
DIRECTOR

Compiled from data obtained from the Lands and Survey Department, and from additional surveys by J. Henderson and M. O'Leary of the Geological Survey Branch of the Mines Department. Geology by J. Henderson and M. O'Leary.



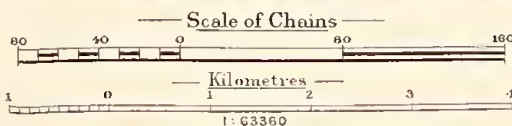


GEOLOGICAL MAP OF UAWA SURVEY DISTRICT



P. G. MORGAN
DIRECTOR.

- Reference
- Roads shown thus
 - Tracks " " "
 - Trigonometrical Stations " " " C 1841
 - Edges of Bush " " "
 - Swamp " " "
 - Water Races " " "
 - Waterfalls and Dams " " "
 - Shafts and Drives " " "
 - Springs " " "



Reference to Geological Colours and Signs

RECENT AND LATE PLEISTOCENE
(Fluvial and estuarine gravels, sands and silts.)
(Beach deposits and raised beaches. Aerial tuff.)
Unconformity.

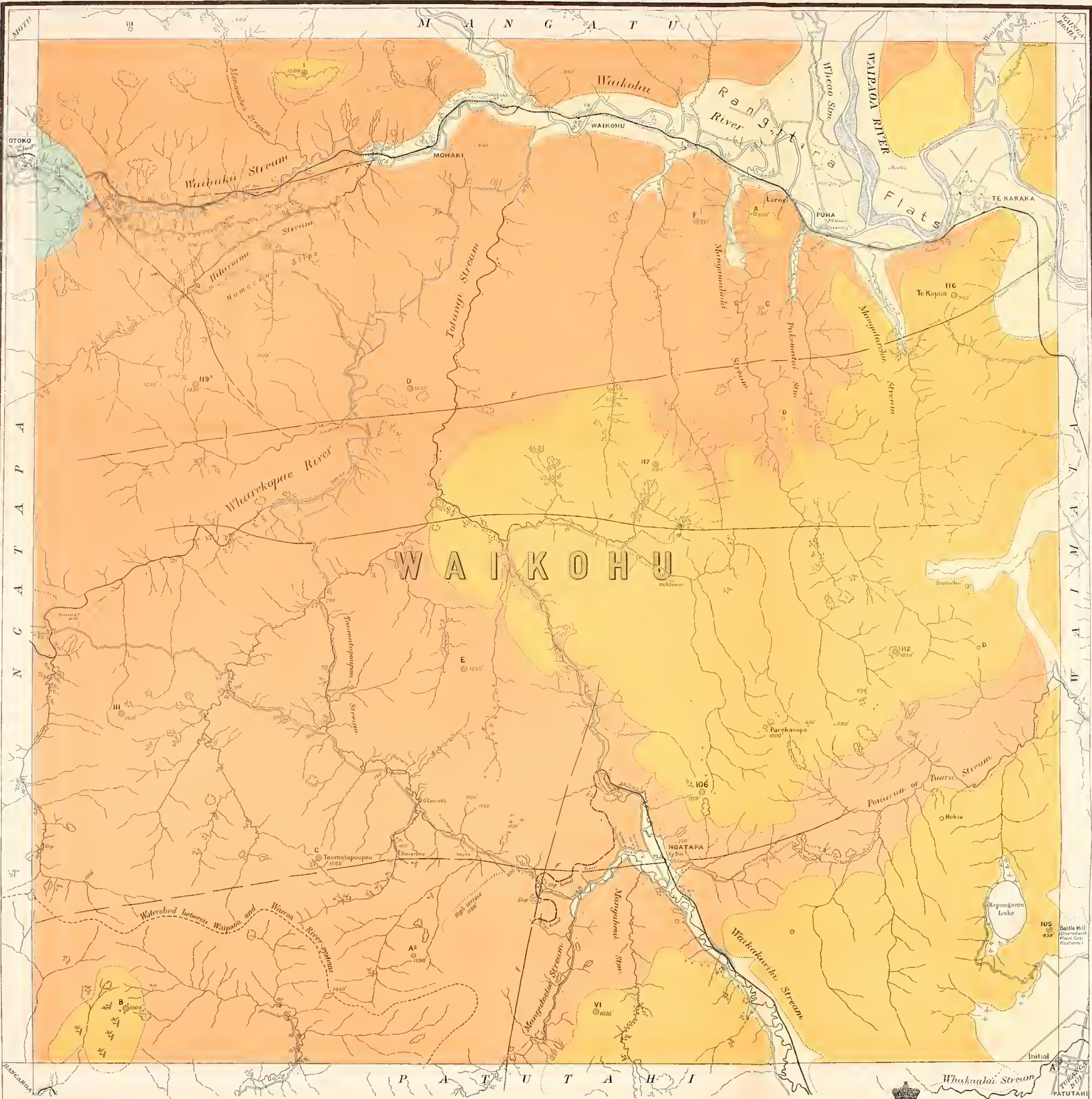
UPPER MIOCENE
(Tawhiti Series.)
Mudstone, argillaceous sandstone, and conglomerate.
Unconformity.
LOWER MIOCENE
(Te Arai Series.)
Mudstone, argillaceous sandstone, and conglomerate.

Outcrops with observed strike and dip.
Outcrops with no observed strike and dip.
Outcrops with vertical bedding.
Outcrops with horizontal bedding.
Quartz veins. None

Extinct Gas Vents.
Faults.

Compiled from data obtained from the Lands and Survey Department, and from additional surveys by J. Henderson and M. Ongley of the Geological Survey Branch of the Mines Department. Geology by J. Henderson and M. Ongley. Ocean contours &c from Admiralty charts.

Compiled and drawn by G. E. Harris, 1917.



GEOLOGICAL MAP OF WAIKOHU SURVEY DISTRICT



P. G. MORGAN.
DIRECTOR.

Compiled from data obtained from the Lands and Survey Department,
and from additional surveys by J.Henderson and M.Ongley
of the Geological Survey Branch of the Mines Department
Geology by J.Henderson and M.Ongley.

Reference

Roads	.....	shown thus	
Tracks	.....	" "	
Trigonometrical Stations	.....	" "	
Edges of Bush	.....	" "	
Swamp	.....	" "	
Water Races	.....	" "	
Railways	.....	" "	
Tram Lines	.....	" "	
Waterfalls and Dams	.....	" "	
Shafts and Drives	.....	" "	
Spring	.....	" "	
Boreholes	.....	" "	

Scale of Chains

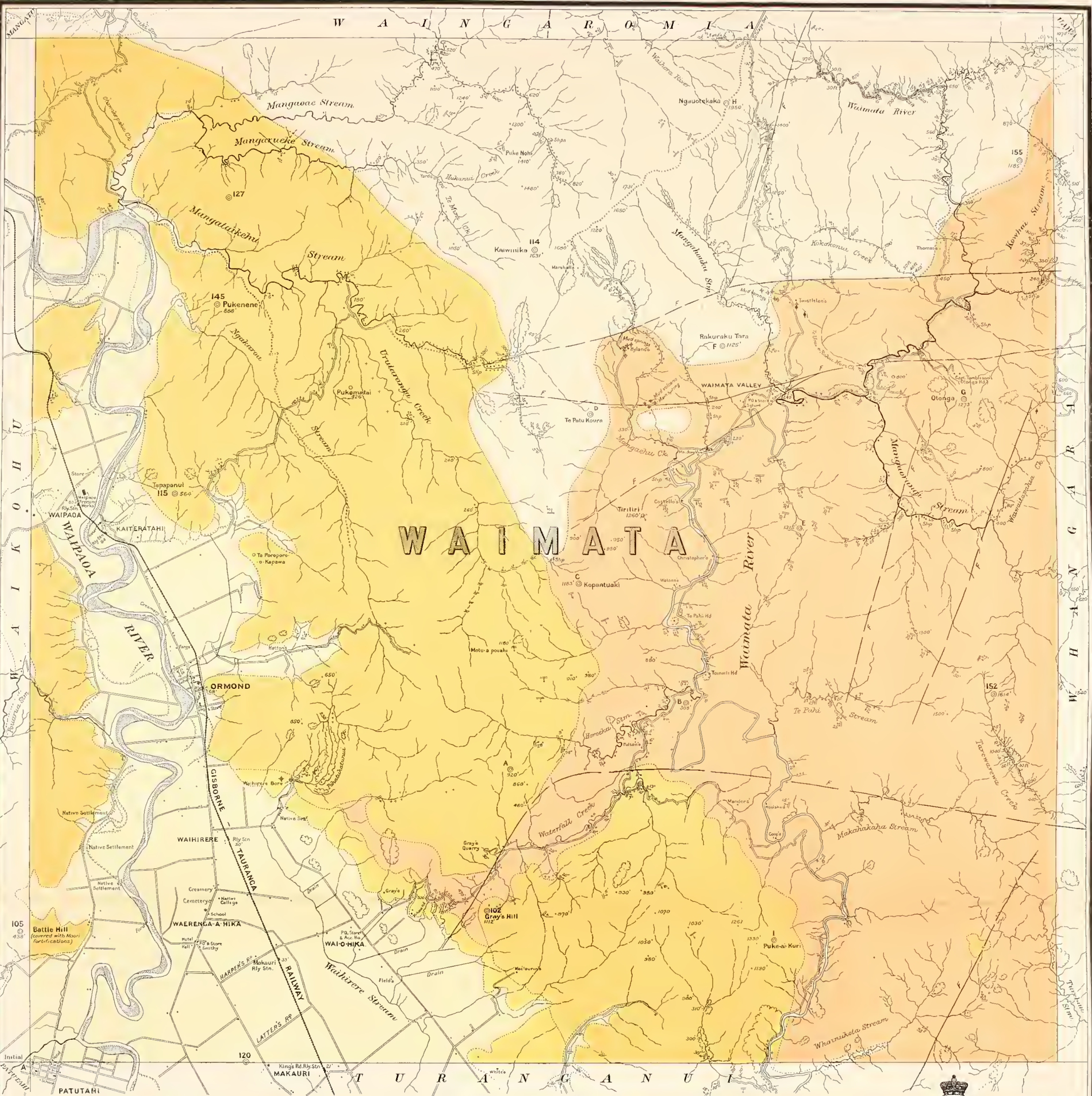
— Reference to Geological Colours and Signs

RECENT AND LATE PLEISTOCENE	{	Fluviatile and estuarine gravels, sands and silts. Beach deposits and raised beaches. Aerial tuff.	
EARLY PLEISTOCENE	{	<i>Walpoea Series.</i> Fluviatile, deltaic, and marine gravels, sands, and silt.	
Unconformity.			

LOWER PLIOCENE { *Ormond Series.*
Limestone, tufaceous and calcareous sandstone, and
mudstone. } .. 
Unconformity.

WER MIOCENE	{ <i>To Aral Series.</i> Mudstone, argillaceous sandstone, and conglomerate. Unconformity.	
E OOCENE (P)	{ <i>Wheozo Series.</i> Shaly mudstone and sandstone.	

Outcrops with observed strike and dip. . . .	
Outcrops with no observed strike and dip. . . .	+ +
Outcrops with vertical bedding.	
Outcrops with horizontal bedding.	= =
Quartz veins.	None.
Extinct Gas Vents.	
Faults.	



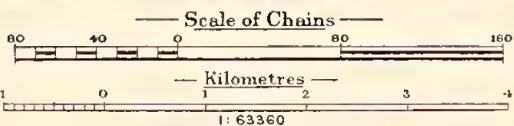
WAIMATA SURVEY DISTRICT



P. G. MORGAN
DIRECTOR

Compiled from data obtained from the Lands and Survey Department, and from additional surveys by J. Henderson and M. Ongley of the Geological Survey Branch of the Mines Department. Geology by J. Henderson and M. Ongley.

- Reference
- Roads shown thus
 - Tracks
 - Trigonometrical Stations
 - Edges of Bush
 - Swamp
 - Water Races
 - Railways
 - Tram Lines
 - Waterfalls and Dams
 - Shafts and Drives
 - Springs
 - Boreholes



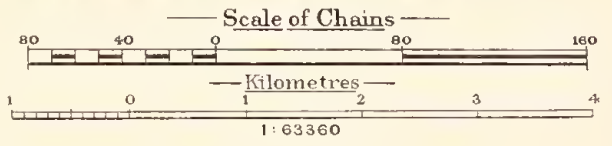
Reference to Geological Colours and Signs

RECENT AND LATE PLEISTOCENE	Fluvialite and estuarine gravels, sands and silts. Bench deposits and raised beaches. Aerial luff.	LOWER PLEISTOCENE	Ormond Series. Limestone, tuffaceous and calcareous sandstone, and mudstone.	UPPER MIOCENE	Tawhiti Series. Mudstone, argillaceous sandstone, and conglomerate. Unconformity.	Outcrops with observed strike and dip.
EARLY PLEISTOCENE	Waipaoa Series. Fluvialite, deltaic, and marine gravels, sands, and silts. Unconformity.			LOWER MIOCENE	Te Anau Series. Mudstone, argillaceous sandstone, and conglomerate. Unconformity.	Outcrops with no observed strike and dip.
						Outcrops with vertical bedding.
						Outcrops with horizontal bedding.
						Quartz veins.
						Extinct Gas Vents.
						Faults.



P. G. MORGAN
DIRECTOR.

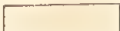
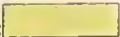
GEOLOGICAL MAP OF WHANGARA SURVEY DISTRICT



— Reference —

- | Roads | shown thus |  |
|--------------------------|------------|--|
| Tracks | " " |  |
| Trigonometrical Stations | " " |  C 189' |
| Edges of Bush | " " |  |
| Swamp | " " |  |
| Water Races | " " |  |
| Waterfalls and Dams | " " |  |
| Springs | " " |  |

— Reference to Geological Colours and Signs —

- RECENT AND
LATE PLEISTOCENE { Fluvialite and estuarine gravela, sands and slits.
Beach deposits and raised beaches. Aerial tuft. } 
- Unconformity.
- UPPER MIOCENE { *Tawhiti Series.*
Mudstone, argillaceous sandstone, and conglomerate. } 
- Unconformity.
- LOWER MIOCENE { *Te Arai Series.*
Mudstone, argillaceous sandstone, and conglomerate. } 
- Unconformity.
- CRETACEOUS { *Mangatu Series.*
Limestone, sandstone, greensandstone, and clay-
shale. } 

- | | |
|---|-----------------------------|
| Outcrops with observed strike and dip..... | $\frac{1}{2}$ $\frac{1}{2}$ |
| Outcrops with no observed strike and dip..... | ++ |
| Outcrops with vertical bedding..... | $\parallel$ |
| Outcrops with horizontal bedding..... | = = |
| Quartz veins..... | None |
| Extinct Gas Vents..... | $\blacklozenge$ |
| Faults..... | $\frac{F}{F}$ |

Compiled from data obtained from the Lands and Survey Department,
and from additional surveys by J Henderson and M Ongle
of the Geological Survey Branch of the Mines Department.
Geology by J Henderson and M Ongle.
Ocean contours &c from Admiralty charts.

Compiled and drawn by G.E.Harris, 1917

LETTER OF TRANSMITTAL.

GEOLOGICAL SURVEY OFFICE,

Wellington, 12th December, 1917.

SIR,—

I have the honour to transmit herewith Bulletin No. 20 (New Series) of the Geological Survey Branch of the Mines Department, entitled "The Geology of the Oamaru District, North Otago," and written by Professor James Park, of Otago University, Dunedin. It contains 124 pages of letterpress, and is illustrated by numerous plates, figures, and maps.

The field-work in connection with the preparation of this bulletin was done by Professor Park, working single-handed, during the summer of 1915-16. The results obtained are lucidly set forth in the following pages; but it is desirable to state that although quite agreeing with most of the conclusions reached, I cannot follow Professor Park in all respects, more particularly in his views regarding the relative ages of the Oamaru and the Waitaki stones.

Professor Park's report must be regarded as a very important contribution to the geological literature of New Zealand. In it special attention has been paid to the palæontology of the various stages of the Oamaruan System, and the lists of fossils given prove conclusively the Middle Cainozoic age of the whole of the system as developed in the Oamaru district.

Practically the whole of the molluscan determinations recorded in this bulletin have been made by Mr. Henry Suter, of Christchurch, Consulting Palæontologist to the Geological Survey. In like manner nearly all the Brachiopods have been named by Dr. J. Allan Thomson, Director of the Dominion Museum.

I have the honour to be,

Sir,

Your obedient servant,

P. G. MORGAN,

Director, New Zealand Geological Survey.

The Hon. W. D. S. MacDonald,
Minister of Mines, Wellington.

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MAP OF
EASTERN OTAGO DIVISION
SHOWING SURVEY DISTRICTS

Districts dealt with in Bulletin No 20

District	"	"	"	"	"	19
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- 1 SAWYER'S BAY
- 2 LOWER HARBOUR WEST
- 3 NORTH-EAST VALLEY
- 4 UPPER HARBOUR WEST
- 5 UPPER HARBOUR EAST
- 6 PORTOBELLO BAY
- 7 OTAGO PENINSULA
- 8 ANDERSON'S BAY
- 9 TOMAHAWK
- 10 TOWN
- 11 UPPER KAIKORAI
- 12 LOWER KAIKORAI
- 13 WAIKARI
- 14 GREEN ISLAND BUSH
- 15 GREEN ISLAND SOUTH
- 16 OCEAN BEACH
- 17 NORTH TUAKITOTO
- 18 TUAKITOTO
- 19 NORTH MOLYNEUX
- 20 SOUTH MOLYNEUX
- 21 INCHCLUTHA
- 22 WAIHOLA
- N.R. Native Reserve

THE GEOLOGY

OF THE

OAMARU DISTRICT,

NORTH OTAGO.

CHAPTER I.

GENERAL INFORMATION.

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The brachiopods were named by Dr. J. A. Thomson, D.Sc., Director of the Dominion Museum, and the Mollusca by Mr. Henry Suter, of Christchurch. In order to obtain consistency in nomenclature the whole of the material was submitted to these specialists, whose determinations give this report a value it could not otherwise possess. For undertaking this laborious work and carrying it out so well the writer wishes to record his thanks, as a small acknowledgment of their services so willingly given towards a better understanding of the Middle Cainozoic geology of New Zealand.

The numerous analyses quoted in this bulletin, except where stated to the contrary, were furnished by Dr. J. S. Maclaurin, D.Sc., Dominion Analyst, to whom the writer has also to acknowledge his indebtedness.

GENERAL DESCRIPTION OF DISTRICT.

The area dealt with in this report comprises a maritime belt bounded on the north by the Waitaki River and on the south by the Kakanui River. It includes the whole of the Oamaru Survey District, the greater portion of the Papakaio Survey District, and a small portion of the Awamoko Survey District.

In its original state the land was mostly covered with native grasses or stunted shrubs. The surface features consist of undulating meadow lands in the southern portion, and of a gently sloping dissected tableland in the northern. The soil is everywhere fertile, and most of it is arable. For the most part the land is divided into small holdings. Throughout the Dominion, North Otago is celebrated for its production of wheat, oats, and potatoes.

The town of Oamaru, with a population of some six thousand inhabitants, is the chief port of North Otago. Duntroon, Peebles, Weston, Enfield, and Kakanui are merely small villages, each with fewer than two hundred and fifty inhabitants.

The district is traversed by the Dunedin-Christchurch trunk railway; and branch lines run to Kurow, Ngapara, and Tokarahi. The whole area is covered with a network of county roads; and narrow settlement roads are numerous, well graded, and mostly in good order.

GENERAL GEOLOGICAL STRUCTURE.

If we disregard the Pleistocene and Recent deposits, which are superficial and have no tectonic significance, there are only two great formations represented in this region—namely, the Kakanuiian, of older Palæozoic age, and the Oamaruian, of Miocene date.

The Kakanuiian consists of mica-schist and altered argillites. The Oamaruian begins with terrestrial beds, which are followed by a great thickness of marine strata. In the neighbourhood of Oamaru the marine beds are intercalated with considerable accumulations of basaltic ash and lava-flows, the result of contemporaneous volcanic eruptions. In no part of New Zealand are rocks of Miocene age so well developed as here, and nowhere in the Dominion do strata of this age contain so many fossiliferous horizons.

The Miocene strata possess a general eastward dip at low angles; and since denudation has been more active against the elevated shore-line than elsewhere, the oldest beds of the series are exposed in the western portion of the district, and the youngest in the eastern or seaward portion.

Besides possessing a general easterly dip, the sheet of Miocene strata is folded along its eastward margin in two gentle corrugations—an anticline and a syncline.

The anticline has been denuded to an area of low relief; and its axis runs along the open down-like Waiareka Valley, drained by the Waiareka Stream, a tributary of the Kakanui River. Passing westward from the sea, the Waiareka anticline discloses in succession the lowermost members of the Miocene series, till eventually the basal conglomerates that rest on the Palæozoic bed-rock are reached.

The syncline forms the Awamoa basin, drained by the Awamoa Stream, which enters the sea a few miles north of the Kakanui River. The Awamoa syncline is a shallow fold, in which the higher members of the Miocene series have been preserved from destruction. To the westward the syncline gradually flattens and then closes.

PHYSIOGRAPHY.

The dominant physiographic features of the Oamaru district are a dissected tableland, table-topped hills, and escarpment ridges.

The dissected tableland extends from the coast near the town of Oamaru in a north-west direction to the Waitaki Valley; and in this distance it rises by a gentle

slope from 240 ft. to 500 ft. above the sea. It is in part an old peneplained land surface, but is mainly a raised ancient flood-plain of the Waitaki River. The Oamaru tableland is a faulted block, bounded on the north by the Waitaki Valley fault. For the most part it is covered with a sheet of Waitaki River gravel varying in thickness from almost nothing to 60 ft.

The gravel rests on a highly eroded surface of the different members of the Oamaruan; and along the coastal front is itself overspread by a thick mantle of newer Pleistocene silts, which gradually thins out going inland.

In the Waitaki Valley between Peebles and Awamoko River the valley-wall is a low ridge of mica-schist, which rises through the gravel sheet and for some ten miles forms part of the tableland. In most places the schist is covered with only a thin scattered covering of fluvial drift. Westward of Awamoko the mica-schist disappears below the lowermost members of the Oamaruan, and westward of the Maerewhenua is outflanked and isolated from the mica-schist area of Central Otago by the overlying argillites and greywackes of the Kakanui Mountains.

This ridge of mica-schist is the truncated stump of a Palaeozoic mountain-chain that ran in a north-west-south-east direction. It is a feature of peculiar interest, as it marks the site and shows the trend of a mountain-system long antecedent to the existing tectonic chains. The Kakanui, Kurow, Mount St. Mary, and Hakataramea mountains are faulted blocks of probably Late Tertiary date. The older Mesozoic rocks, of which they are mainly composed, contain no associated quartzose conglomerates; and from this it may be postulated that the Palaeozoic mica-schist chain was already worn down to a feature of low relief, and perhaps submerged, before the deposition of the Mesozoic sediments.

The thick layers of quartz sands, quartz gravels, and quartzose conglomerates at the base of the Oamaruan in this area were in part derived from the erosion of the mica-schist chain after its emergence from the sea towards the close of the Mesozoic epoch, and in part, or perhaps mainly, from the denudation of the Kakanui and Kurow mountains, which contain a great thickness of quartzites and quartzose rocks. It was probably during this period of erosion that the truncation of the mica-schist chain took place. Its final erosion was completed by the Waitaki River at a time when the land stood some 300 ft. lower than at present.

The great mica-schist peneplain of Central Otago, on the broad surface of which rise long faulted blocks that form conspicuous table-topped block mountains, is itself the truncated stump of a massive Palaeozoic chain that also ran transversely to the existing axial divide. What tectonic relationship existed between the ancient Maniototian chain and the Awamokoan chain is not easy to discover. Probably both belonged to the same orographical system, the smaller Awamokoan being an outlying pucker or forefold of the dominating Maniototian chain.

The Oamaru tableland is deeply dissected. Where the softer rocks of the Oamaruan are well developed there are many fine examples of valleys of erosion, some of which possess beautiful forms that are the resultant of transverse and longitudinal catenary curves. But where the harder volcanic breccias, lavas, or limestones rise near the surface of the tableland, instead of broad valleys with gently sweeping curves we have narrow gorges with steep rocky walls.

Above the level of the tableland near Cape Wanbrow there rises a monadnock of tuff, breccia, and basaltic lava. This pile of volcanic material stood in the ancient estuary of the Waitaki, and divided the stream into two main channels, one of which entered the sea to the north, and the other to the south-east near Kakanui.

In the upper basin of the Oamaru Creek the Awamoan syncline is closed. From the saucer-shaped basin the Oamaru limestone rises gently to the south-west, west,

and north-west till it reaches the rim of the basin. Here the limestone ends abruptly, forming a line of steep escarpment.

The limestone rim of the basin is breached at Cave Valley, at Teaneraki, west of Brockman's Hill, and between Brockman's Hill and Tabletop Hill. These breaches were made by streams which entered the basin when the land stood at a lower level, and before erosion on the landward side had cut down the Waiareka tuffs and quartzose conglomerates, whereby the Waiarekan anticline was worn down and the drainage diverted to the Kakanui River.

COAST-LINE.

From Oamaru a narrow coastal plain extends northward to the Waitaki Valley. This plain lies from 15 ft. to 25 ft. above sea-level, and is composed of Pleistocene silt. Since the surveys made in 1858 the sea has encroached on the land as much as 50 yards at places about half-way between Oamaru and Pukeuri. At the present time the sea face of the plain is everywhere steep, which may be taken as an evidence that erosion is relatively rapid. Fortunately, the toe of the silt-cliff is protected by an apron of coarse gravel drift piled up by high tides and easterly storms. As it is, the sea is gradually nibbling away the edge of the plain, the recession being most rapid in those portions subject to the sweep of the prevailing north-travelling ocean currents of the east coast. At such places measures will have to be taken in the near future to reduce the rate of erosion, as the encroachment, if unhindered, will lead to the destruction of much valuable land.

Behind the narrow strip of coastal plain on which Oamaru stands, rises somewhat abruptly the frayed edge of the Oamaru tableland. At a time of no great antiquity the sea washed against the edge of the tableland; and since the last uplift of the land it has unceasingly striven to cut away the narrow coastal plain that at present lies between it and its old shore-line.

From Oamaru Breakwater southward to Kaiarero Creek, a distance of three miles, the coast is bounded by high precipitous cliffs carved in the tuffs, breccias, and lavas of Cape Oamaru. These volcanic rocks form a bold promontory which deflects the coastal currents seaward, thereby protecting from complete destruction the softer Tertiary rocks and Pleistocene deposits lying to the north of Oamaru. In a similar manner the promontory of tuffs and breccias at Kakanui has sheltered the softer rocks occupying the coast-line between Kakanui and Cape Oamaru.

Where volcanic rocks occupy the coast-line the sea has worn away the edge of the land into a wide platform or plane of marine erosion. This rock-platform slopes gently towards the sea; and a wide expanse of it may be seen at low water between Cape Wanbrow and Oamaru Breakwater, and also on the coast a mile north of Kakanui.

A few hundred yards north of Kaiarero Creek, at Cape Wanbrow, and again between Boatman's Harbours and Oamaru, there is a raised beach resting on an uplifted plane of marine erosion lying about 12 ft. above high-water mark. On the raised beach rests more or less talus, composed mainly of Pleistocene silt that has trailed down the adjoining slopes.

GEOLOGICAL LITERATURE.

The first notice of the geology of the Oamaru district is contained in a paper by Dr. Gideon Algernon Mantell, F.R.S., published in the *Quarterly Journal of the Geological Society* in 1850.* The notes and collections of moa and other bird bones, of rock

* "Notice of the Remains of the Dinornis and other Birds, and of Fossils and Rock Specimens, recently collected by Mr. Walter Mantell in the Middle Island of New Zealand; with Additional Notes on the Northern Island. By Gideon Algernon Mantell, Esq., LL.D., F.R.S., F.G.S., &c. With Note on Fossiliferous Deposits in the Middle Island of New Zealand, by Professor E. Forbes, F.R.S., &c." *Quart. Jour. Geol. Soc.*, vol. vi, 1850, pp. 319-343; 2 plates, 7 figs.

specimens, fossil shells, Polyzoa, and Foraminifera that form the basis of the paper were made by the Hon. Walter Mantell in 1848, during a journey from Kaiapoi, in Canterbury, to the Molyneux River, in South Otago, as Government Commissioner for the settlement of Native land claims. The geological sketch-map of this long stretch of coast-line, with which the paper is illustrated,* is the first geological map of any portion of New Zealand. The formations distinguished by Mr. Mantell in the area lying between the Waitaki and Kakanui rivers are,—

Tertiary blue clay [= Awamoan].

Ototara limestone [= Oamaru stone].

Quartz conglomerate.

Slate.

He records the occurrence of the volcanic tuff at Kakanui Point,† and mentions that it contains a great variety of crystalline minerals, as hornblende, augite, garnets, &c.

In 1859 Professor Huxley, F.R.S., described some bones of a small whale and of a gigantic penguin from the Kakanui limestone, sent to him by Mr. Walter Mantell. Referring to the age of the Tertiary rocks at Kakanui he says,‡ “The marine shells contained in the blue clay [All Day Bay clay] and the limestone [Kakanui] are different from those now living in the seas of New Zealand. It would appear, therefore, that the Kakanui limestone is at least of Pliocene age, if not, as Mr. Mantell suspects, much older.”

In 1863 Sir James Hector (at that time Provincial Geologist for Otago), in his narrative of his explorations on the west coast of Otago, correlates the Waiau Tertiary limestone with the Oamaru and Caversham limestones.§

In 1864 Sir James Hector produced a manuscript geological map of Otago and Southland on which the distribution of the Palæozoic and Tertiary formations is shown. This map was never published, but the original is in the Otago Museum, and there is a copy in the Dominion Museum, Wellington. On this map the Oamaru Tertiary rocks are referred to the Miocene.

In 1865 a collection of fossils from the tuffs and marine strata of Cape Oamaru, exhibited by the Otago Geological Survey in the New Zealand Exhibition|| held at Dunedin in that year, was referred to the “Upper Marine Pliocene(?)”

In 1869 Mr. Charles Traill made a large collection of fossil shells from the blue clays¶ overlying the Oamaru stone at the Rifle Butts, south of Cape Wanbrow. He identified seventy-seven genera, of which he believed fifty-one to be extinct and twenty-six perhaps alive. Probably the word “genera” used by him should be read as “species.” When referring to the age of the beds he believed that the fossils indicated a greater antiquity than the Pliocene.

In 1870 Sir James Hector, then Director of the Geological Survey of New Zealand, in his catalogue of the Colonial Museum, classified the Tertiary rocks of the Dominion in three groups—

B. Upper or Struthiolaria beds.

C. Middle or Cucullæa beds.

D. Lower or Ototara Series.

* *Quart. Jour. Geol. Soc.*, vol. vi, 1850, p. 320, fig. 1.

† *Ibid.*, p. 324, figs. 3 and 4.

‡ Thomas H. Huxley, F.R.S.: “On a Fossil Bird and a Fossil Cretacean from New Zealand.” *Quart. Jour. Geol. Soc.*, vol. xv, 1859, pp. 670–77; 1 plate.

§ *Otago Provincial Government Gazette*, 5th Nov., 1863.

|| New Zealand Exhibition: *Juror's Reports and Awards*, 1865, p. 263.

¶ Charles Traill: “On the Tertiary Series of Oamaru and Moeraki.” *Trans. N.Z. Inst.*, vol. ii, 1870, pp. 166–169.

In 1871 the same writer, in a paper* describing the discovery of some bones of the gigantic fossil penguin *Palæudyptes antarcticus* Huxley in the Cobden limestone, classified that rock as belonging to the Ototara Series—the uppermost member of a group of strata to which he applied the term “Cretaceo-Tertiary.”

In 1872 Captain F. W. Hutton published a synopsis† of the younger formations of New Zealand, in which the Ototara group of beds is referred to the Upper Eocene.

In 1875 Captain Hutton, at that time Provincial Geologist for Otago, in his official report on the geology of Otago, referred the Oamaru Formation to the Lower Miocene, and subdivided it into two groups—

Oamaru Formation { Trelissic group.
Ototara group.

The Ototara group‡ comprised (a) the Oamaru limestone, and (b) the overlying “hard crystalline shelly limestone”—the Kakanui limestone of this report. His Trelissic group§ consisted of conformably overlying calcareous conglomerates, green and yellow sandy clays in places interstratified with volcanic rocks, “the whole being again covered with limestone.”

In 1877 Mr. Alexander McKay, F.G.S., at that time a field geologist of the New Zealand Geological Survey, made extensive collections of fossils in the Oamaru and Waitaki districts.|| At the same time he conducted a geological reconnaissance of the region lying between the Waitaki and Kakanui rivers, and produced a geological map on which he subdivided the Tertiary marine strata into five groups¶—

Lower Miocene ..	1. Awamoa and Pareora beds.
Upper Eocene ..	2. Hutchinson Quarry and Mount Brown beds.
	(3. Ototara limestone.
Cretaceo-Tertiary ..	4. Tuffs, volcanic rocks, and greensands.
	(5. Coal-beds, grits, &c.

In this report McKay mentions all the salient geological features of the district; and it is noteworthy that the succession of the Tertiaries recognized by him at this time has never been seriously challenged. He notes that the Hutchinson Quarry limestone represents a calcareous horizon overlying the Ototara limestone, that the volcanic tuffs and basalts in the neighbourhood of the town of Oamaru are associated with the Hutchinson Quarry limestone, and that the Waiareka tuffs underlie the Ototara limestone.

McKay's assignment of a Cretaceo-Tertiary age to the Ototara limestone and underlying Tertiary beds at Oamaru was not the result of a careful review of the palæontological evidence; and there is no internal evidence in his report to show the reasons for referring these beds to that hyphenated age. We can only suppose that this age-name was adopted in deference to the official chronological classification** of the Geological Survey, which ascribed this age to rocks at Waipara and Weka Pass that were believed to be the correlatives of the Oamaru rocks.

From 1877 to 1887 there was considerable geological activity in and around the Oamaru district. Then followed a long period during which there was an almost complete cessation

* James Hector, F.R.S.: “On the Remains of a Gigantic Penguin (*Palæudyptes antarcticus* Huxley) from the Tertiary Rocks on the West Coast of Nelson.” *Trans. N.Z. Inst.*, vol. iv, 1872, pp. 341–346.

† F. W. Hutton, F.G.S.: “Synopsis of the Younger Formations of New Zealand.” *Rep. Geol. Explor. during 1871–72*, No. 7, 1872, pp. 182–184.

‡ “Report on the Geology and Goldfields of Otago,” 1875, pp. 46–47.

§ *Ibid.*, p. 47.

|| A. McKay: “Oamaru and Waitaki Districts.” *Rep. Geol. Explor. during 1876–77*, No. 10, 1877, pp. 41–66 (with map).

¶ *Ibid.*, Map facing p. 50. (Scale, 1 in. = 4 miles.)

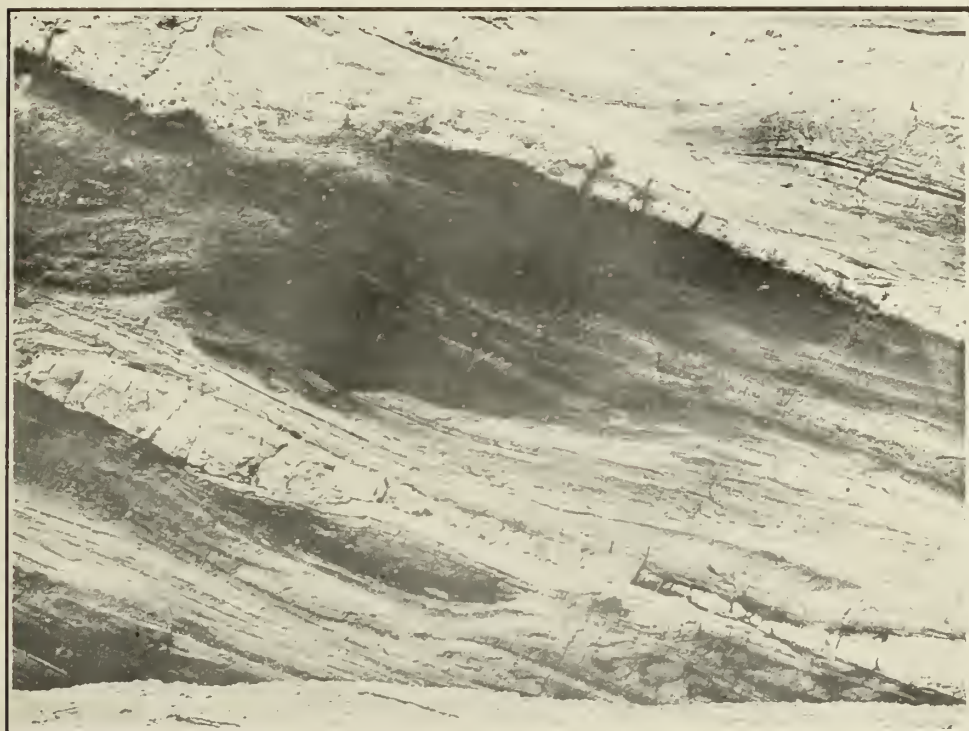
** “Classification adopted by Geological Survey Department.” Appendix I, *Rep. Geol. Explor. during 1877–78*, No. 11, 1878, pp. 189–198.

PLATE I.



A. C. Gifford, photo.]

A. THIN-BEDDED TUFFS SOUTH OF CAPE WANBROW.



A. C. Gifford, photo.]

B. CURRENT-BEDDED TUFFS NORTH OF CAPE WANBROW.

of work dealing with the stratigraphical and palæontological side of New Zealand geology. This period of inactivity was broken by the author when he undertook, in 1903 and 1904, the field-work connected with his investigation of the marine Tertiary rocks of Otago and Canterbury.* Since 1905 much valuable information relating to the Middle and Lower Tertiary rocks of New Zealand has appeared in the bulletins of the Geological Survey, and in papers published in the *Transactions of the New Zealand Institute* and elsewhere.

The reports and papers published since 1877 that have a bearing on the geology or palæontology of the Oamaru district are given below—

1880. Tenison-Woods, J. E.: "Corals and Bryozoa of the Neozoic Period in New Zealand." 4 plates. Wellington, 1880.
1882. McKay, Alexander: "Geology of the Waitaki Valley and Parts of Vincent and Lake Counties." *Rep. Geol. Explor. during 1881*, No. 14, pp. 56-92.
1882. McKay, Alexander: "On the Younger Deposits of the Wharekuri Basin and the Lower Waitaki." *Ibid.*, pp. 98-106.
1882. Hector, James: "Index to Fossiliferous Localities in New Zealand." *Ibid.*, pp. 118-128.
1884. McKay, Alexander: "On the North-eastern District of Otago." *Rep. Geol. Explor. during 1883-84*, No. 16, pp. 45-66.
1885. Hutton, F. W.: "Sketch of the Geology of New Zealand." *Quart. Jour. Geol. Soc. Lond.*, vol. xlv, pp. 191-220.
1886. Hutton, F. W.: "The Mollusca of the Pareora and Oamaru Systems of New Zealand." *Proc. Linn. Soc. N.S.W.*, ser. 2, vol. i, pp. 205-237.
1886. Hector, James: *Outline of New Zealand Geology*. With coloured geological map and numerous figures; p. 98.
- 1886-87. Grove, E., and Sturt, G.: "On Deposit of Diatomaceous Earth at Cormack's Siding, near Oamaru, N.Z." *Jour. Quekett Micro. Club*, 16th Sept., 1886; 17th Jan., 1887; 18th May, 1887; and 19th Aug., 1887.
1887. Hutton, F. W.: "Geology of the Country between Oamaru and Moeraki." *Trans. N.Z. Inst.*, vol. xix, pp. 415-430.
1887. McKay, Alexander: "On the Younger Secondary and Tertiary Formations of Eastern Otago—Moeraki to Waikouaiti." *Rep. Geol. Explor. during 1886-87*, No. 18, pp. 1-23.
1887. Hutton, F. W.: "On the Greensands of the Waihao Forks." *Trans. N.Z. Inst.*, vol. xx, pp. 264-267.
1889. de Lautour, H. A.: "On the Fossil Marine Diatomaceous Deposit near Oamaru." *Trans. N.Z. Inst.*, vol. xxi, pp. 293-311; 6 figs.
1889. Grunow, A.: "Some Critical Remarks by Herr A. Grunow on the Oamaru Diatom Papers of Messrs. Grove and Sturt." *Jour. Quekett Micros. Club*, vol. iii, ser. 2, p. 387, No. 24, April, 1889.
1891. Ettingshausen, C. von: "Contributions to the Knowledge of the Fossil Flora of New Zealand." *Trans. N.Z. Inst.*, vol. xxiii, pp. 237-310; 9 plates.
1891. Hinde, G. J., and Holmes, W. Murton: "On the Sponge-remains in the Lower Tertiary Strata near Oamaru, Otago, New Zealand." *Linn. Soc. Jour.*, Zoology, vol. xxiv, pp. 178-262; 9 plates.
1900. Hutton, F. W.: "The Geological History of New Zealand." *Trans. N.Z. Inst.*, vol. xxxii, pp. 159-183.

* James Park: "On the Marine Tertiaries of Otago and Canterbury, with Special Reference to the Relations existing between the Pareora and Oamaru Series." *Trans. N.Z. Inst.*, vol. xxxvii, 1905, pp. 489-551; 1 plate, 17 figs.

1904. Boehm, G.: "Über Tertiäre Brachiopoden von Oamaru, Südinsel Neuseeland." *Zeitschr. d. deutsch. geol. Gesellsch.* lvi, Briefl. Mitt. 146-150; 1 plate.
1905. Park, James: "On the Marine Tertiaries of Otago and Canterbury, with Special Reference to the Relations existing between the Pareora and Oamaru Series." *Trans. N.Z. Inst.*, vol. xxxvii, pp. 489-551; 1 plate, 17 figs.
1905. Park, James: "Description of a New Species of Pecten [*Pecten huttoni*] from the Oamaru Series." *Trans. N.Z. Inst.*, vol. xxxvii, p. 485.
1905. Park, James: "On the Geology of North Head, Waikouaiti, and its Relation to the Geological History of Dunedin." *Trans. N.Z. Inst.*, vol. xxxvi, pp. 418-430; 1 fig.
1906. Thomson, J. A.: "The Gem Gravels of Kakanui; with Remarks on the Geology of the District" [Otago]. *Trans. N.Z. Inst.*, vol. xxxviii, pp. 482-495.
1907. Thomson, J. A.: "Inclusions in some Volcanic Rocks" [Dolerite: Portrush (Co Antrim) and Kakanui (N.Z.)]. *Geol. Mag.*, Dec. v, vol. iv, pp. 490-500.
1908. Thomson, J. A.: "Fossils from Kakanui." *Trans. N.Z. Inst.*, vol. xl, pp. 309-332; 2 plates.
1909. Park, James: "Outline of the Geology of New Zealand." *N.Z. Mines Record*, Feb., Mar., April, 1909.
1910. Park, James: *Geology of New Zealand*. Whitcombe and Tombs, Christchurch, N.Z. 27 plates, 145 figs., and coloured geological map of New Zealand.
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OUTLINE OF GEOLOGY.

The oldest rocks are phyllites and mica-schists, probably of Early Palæozoic age. On the highly denuded surface of these ancient rocks there rests a great succession of Middle Tertiary strata belonging to the Oamaruan System. The lowermost rocks of the Oamaruan are quartzose gravels and sands that contain a bed of fireclay and a seam of lignite. In their uppermost horizon the gravels have been consolidated by the infiltration of chalybeate waters into limonitic conglomerate. In some places the quartzose sands are compacted into soft sandstones.

These quartzose drifts and conglomerates constitute the lignitic measures of the Oamaruan. Overlying them conformably is a great succession of marine sediments—arenaceous, argillaceous, and calcareous—with which are intercalated beds of volcanic mud and ash and flows of basaltic lava. The pyroclastic deposits are of great thickness near the centres of volcanic activity: but they thin out rapidly along the radii diverging from the foci.

Volcanic activity began at the close of the lignitic period, and continued intermittently till near the beginning of the Hutchinsonian stage. And while showers of ash slowly piled up a great thickness of pyroclastic material around the centres of eruption, the deposition of true marine sediments continued uninterruptedly on that portion of the sea-floor lying between the area affected by volcanic activity and the ancient shore-line. At the sources of Oamaru Creek the Waiareka tuffs rest directly on the quartzose lignitic series; while between the sources of the Waiareka and the Kakanui River, and also in the Waitaki Valley near Black Point, we find the normal succession of marine sandy beds and clays following the lignitic series, and passing upward to the base of the Ototara limestone. The volcanic vents were situated on the floor of the sea, many miles seaward of the old shore-line. Contemporaneous organic remains occur in many of the consolidated ash-beds, which may be taken as

an evidence that the volcanic activity took the form of many small outbursts of fragmentary material, with periodic greater displays accompanied by the effusion of lava-streams.

For two long periods and several short periods there was a complete cessation of activity; and during these times marine deposits, with their marine life, encroached on the volcanic area.

The sporadic deposits of pyroclastic material which are intercalated with the middle Oamaruan have a disturbing influence on the succession of the purely marine sediments; but this disturbance has its compensations. During the period of quietude that followed the outbursts of the Waiarekan stage, "coral reefs"* established themselves on the platform of Waiarekan tuffs, and outside the volcanic zone their growth continued without interruption till the Hutchinsonian. But while the polyzoans flourished in the clear waters of the outer sea, volcanic activity began again in the Oamaru and Kakanui areas, and soon provided conditions which led to the invasion of these areas by a rich molluscan fauna. Hence it is that portions of the Ototaran are represented near the centres of eruption by contemporaneous tuffs containing the remains of a varied molluscan life. These molluscs enable us to compare the life of Ototaran times with that of the Awamoan and Waiarekan.

On the deeply eroded surface of the different members of the Oamaruan there rests a thick sheet of fluviatile gravel. Over this drift lies an irregular covering of fine yellow silt.

CLASSIFICATION.

Table of Formations.

Recent	..	..	..	Sands and gravels forming river-flats.
Newer Pleistocene	..	..	{	(a.) Yellow silts.
Older Pleistocene	..	..	{	(b.) Raised beaches.
				High-level gravels and sands.
		Awamoan	..	Soft sandstones, sandy clays, blue clays, and shelly sands.
		Hutchinsonian	{	(a.) Calcareous sandstone, often glauconitic (= Waitakistone).
			{	(b.) Greensands.
			{	(c.) Conglomerate (basaltic near Oamaru).
				Kakanui limestone (with layers of tuff in volcanic area).
		Ototaran	{	Oamaru limestone (intercalated towards close with tuffs containing rich molluscan fauna between Deborah and Kakanui; and around Oamaru replaced by lavas and tuffs).
Miocene (Oamaruan)			{	(a.) Marly clays and sandstones
		Waiarekan	{	(b.) Sandstones (often micaceous) with hard nodules and lenses containing rich molluscan fauna
				Represented by Waiareka tuffs and lavas in volcanic area.
		Ngaparan†	..	Quartzose conglomerates and sands; sandstones and fire-clay with lignite.
Palæozoic	..	Kakanuiian	..	Mica-schist and phyllites.

GEOLOGICAL HISTORY OF OAMARU DISTRICT.

By "geological history" is meant the attempt to depict the distribution of the land and water at the different epochs of geological time, to reconstruct the outline and physical features of the dry land, to clothe the land with vegetation, and people the seas with life, and lastly, from a study of the character of the contemporary vegetation and marine life, to indicate the probable climatic conditions prevailing at the time.

* The Oamaru stone and similar limestones have frequently been referred to as "coralline." More correctly they are bryozoan or polyzoan rocks, but the term "coral reef" may occasionally be used on later pages as a familiar term in a conventional sense.

† The "ng" is nasal, and the word is pronounced almost as "Naparan."

The problem of reconstruction is always difficult. Even in Eurasia and North America, where a vast amount of data has been gathered in the past century, the pictures are, at best, dim outlines in which the forms are shadowy and often unreal. The reasons for this unreality are in part due to the wide gaps in the geological record, and in part to the relative smallness of the existing dry-land areas compared with the size of the ocean basins.

In such matters as the simple principles of erosion and formation of stratified rocks we are on sure ground, for we are able to apply present conditions to the past; but when we come to investigate the causes and directions of crustal movements and earth-folding we immediately find ourselves in difficulties. On all sides we see the effects of folding and crustal dislocations. We soon discover that at one epoch the axis of the folded chains persistently followed a well-defined course that later research proves to have no apparent relationship to the major folds of the next epoch.

The existing crustal folds and structural dislocations took place before man appeared on the earth; and so far as the limited span of human life is concerned, the forces to which the present structure is due may be said to have expended themselves. Perhaps they are not expended, but only dormant. At any rate, all we are conscious of are the effects spread out before us like a vast stereotype.

Our inability to unravel the dynamics of rock-folding is due in no small measure to our profound ignorance of the earth's subcrustal condition. There is a good deal of evidence in favour of the belief that the dynamics of earth-movements may be governed partly by the conditions existing below the lithosphere, and partly by the disturbance of the isostatic balance arising from the denudation of mountain-folds, thereby lightening the load, and the transportation of the waste to the ocean-floor along the fringe of the land. In this way the load is increased on a narrow segment. The overloaded segment will gradually sink, and the subsidence will be compensated by a corresponding uplift of the adjacent dry land.

The effects resulting from a disturbance of the isostatic balance are well known in coal-mining. Take the case of a flat-lying seam of coal being worked at a considerable depth below the surface. Before the breaking-out of the coal begins there is no movement in the rocks lying above or below the seam, since a condition of isostatic equilibrium exists. When the galleries are driven the static balance is disturbed, and an additional load is thrown on the pillars. If the coal is strong and the floor weak the pillars sink, and the floor of the galleries rises, producing what miners call "creep." The rise of the floor continues till the galleries are filled, when static equilibrium is once more established.

Rock-folding must have taken place under the pressure of an external load of sufficient magnitude to prevent rupture during the progress of the movement. By the removal of a portion of the external load by denudation the stresses in the arches of the rock-folds would express themselves in the rupture and dislocation of the component rocks.

It is certain that the pile of strata composing the great axial chain of folded mountains of New Zealand could not be derived from the denudation of a small oceanic island of like size. Only land-masses of continental dimensions could provide the vast amount of detrital material represented in this and other great folded chains of the globe. The material is marine, estuarine, and deltaic; hence we know that each of the existing chains stands on what was at one time a sea-floor that ran along the shores of some pre-existing land-mass.

Many of the problems met with in the investigation of the geological history of New Zealand are almost insoluble. The conditions existing in the Palæozoic and Mesozoic epochs are veiled in obscurity, this arising from the circumstance that

New Zealand is merely an elongated residual block of a greater land now submerged below the sea. The difficulties that beset the reading of the geological history of New Zealand are multiplied many-fold when we come to deal with a corner of that terrain; and it may be sometimes necessary to travel farther afield to gather the data needed for the connected story, and so it is now: the evidence relating to the earlier geological history of Oamaru is to be found outside the limits of the area dealt with in the present report.

In both form and size the New Zealand of the Palæozoic and Mesozoic was constantly changing, and it was not till the Middle Cainozoic that the land assumed the general outline of its present form. Since then the story becomes clearer and clearer as we approach the present day.

Before the beginning of the Cainozoic the history is obscure, and some of it cannot be written, through the lack of data. Many of the geological records have been destroyed by denudation or buried, and some never existed in the present New Zealand terrain. In some measure the geological history of the Oamaru terrain is the story of a great portion of the South Island.

It is certain that the most ancient rocks in north-east Otago do not appear at the surface. The occurrence of fragments of gneiss and other crystalline schists together with ultra-basic eruptive rocks of an ancient type in the Kakanui tuffs and breccias of the Ototaran stage, first recorded by Thomson* in 1905, affords conclusive evidence that a complex of older Palæozoic rocks exists below the Cainozoic strata in the coastal region of Oamaru. If these crystalline schists bear the same relationship to the Awamokoan schists of the Waitaki Valley as the crystalline schists of south-west Otago bear to the Maniototian schists of Central Otago, then the buried crystalline rocks at Kakanui are older than the Awamokoan schists.

Triassic conglomerates largely composed of granite, gneiss, and crystalline schists occur in the East Cape district of the North Island, near Otorohanga in the King-country, and at Kawhia. These occurrences, with those known in the South Island, would lead to the belief that the basal rocks of both Islands are a complex of ancient crystalline rocks arranged in a great north-east-south-west synclinal fold, in the trough of which the later Palæozoic and older Mesozoic rocks are entangled and folded. In this view New Zealand is merely a faulted block mountain standing on a platform of ancient crystalline rocks, of which only a remnant now remains at the surface, as in south-west Otago, and bounded on the edge of the submarine shelf by powerful faults.

The oldest rocks in North Otago are the mica-schists that form the truncated ridge lying between Big Hill and Black Point. The mica-schists are well exposed at Georgetown and in the Awamoko Gorge. They strike north-west-south-east—that is, parallel with the axis of the ridge—and dip north-east. In general character and appearance these schists are indistinguishable from the Maniototian mica-schists of Central Otago. North-westward they disappear below the Middle Tertiary Oamaruan.

Between Kurow and Otekaieke rivers there appear flaggy mica-schists, perhaps somewhat less altered than the Awamoko schists. Following these, on the east and north-east side of the Kakanui Mountains, there are red and green micaceous quartzites.† West of these, and lying on them conformably, are rocks of a subschistose character that appear to have been originally slaty breccias and sandstones. The higher portions of these altered rocks are associated with blue fissile slates near Otepopo, and with a hard crystalline limestone near Dunback.‡

* J. A. Thomson: *Trans. N.Z. Inst.*, vol. xxxviii, 1906, p. 492.

† A. McKay: *Rep. Geol. Explor. during 1883-84*, No. 16, 1884, p. 52.

‡ A sample of hard blue limestone resembling that from Dunback was sent to the author in the early part of 1917. It was stated to come from Block X, Maerewhenua Survey District.

In the section across the Kurow Mountains, in the line of Mount St. Mary, we have, at the foot of the range, pale grey and blue silky phyllites.* To the westward these are overlain by a great thickness of flaggy quartzites and altered argillites that are followed, in ascending order, by altered greywacke and beds of altered pale-green aphanitic breccia containing thin bands of red and green slaty shale, which are in many places streaked with jasperoid segregations. Above these lie blue silky slates that alternate with thin quartz folia.†

Overlying a great thickness of this singular slate and quartz series there occurs a thin-bedded siliceous sandstone, almost a quartzite, alternating with thin quartz folia. Above these lies the Mount St. Mary Series, consisting of coarse gritty sandstones, conglomerates, slaty breccias, slaty and flaggy argillites slightly micaceous and containing two fossiliferous bands.

The strike throughout is about north-west-south-east and the dip south-west. At the foot of the range the angle of dip of the more altered rocks is 65° or more, but to the westward the inclination gradually flattens till at the foot of Mount St. Mary it is not more than 35° . Higher up the slopes of Mount St. Mary the angle of dip increases, and near the summit of the range is 60° .

The total thickness of rocks exposed in this fine section is not less than 10,000 ft., and is probably much greater. The whole of this pile of strata appears to form a continuous and conformable succession, all the members of which are more or less altered, the metamorphism being greatest at the base of the succession.

The highly altered schistose rocks at the base of the succession constitute the "Kurow Schists" of McKay, the "Kakanui Series" of Hector, and the "Arahura Series" of Bell and Fraser.‡ The aphanitic sandstones and breccias, red and green slaty shales, and greywackes probably represent the Te Anau or Maitai Series of the old Geological Survey, now known to be of Carboniferous or Permo-Carboniferous age. The Mount St. Mary Series is probably Triassic or Permo-Triassic.

The relationship of the mica-schists forming the worn-down Awamoko ridge to the Kakanui cannot be determined in this terrain, as the two formations do not, so far as known at present, come in contact with one another; but in other parts of Otago the Kakanui appears to be conformable to and to pass imperceptibly into the more highly altered Maniototo schists.

The Awamoko mica-schists have been so highly altered that it is impossible to discover what was the character of the material of which they were originally formed. The material may have been a succession of muds and sands, or of pyroclastic tuffs and breccias, acidic in composition. The composition of the overlying Kakanui, Maitai, and Mount St. Mary series presents less difficulty. The original constituent materials were clays, sands, and gravels, with perhaps the exception of the aphanitic breccias of the Maitaian, which may possibly have been pyroclastic.

There are only two known fossiliferous horizons in the Mount St. Mary Series. No fossils have been found in the underlying altered rocks. If they ever existed they have been obliterated by the metamorphism the original sediments have undergone. The presence of the Dunback limestone in the Maitaian may be accepted as an evidence that the younger Palaeozoic sea was neither limeless nor without life. Possibly this rock may mark the site of a Palaeozoic coral reef.

* J. Park: "On the Discovery of Permo-Carboniferous Rock at Mount St. Mary, North Otago." *Trans. N.Z. Inst.*, vol. xxxvi, 1904, pp. 447-553.

† *Loc. cit.*, p. 449.

‡ J. M. Bell and C. Fraser: "The Geology of the Hokitika Sheet, North Westland Quadrangle." *Bull. No. 1 (N.S.). N.Z. Geol. Surv.*, 1906, pp. 19, 40 *et seq.* See also P. G. Morgan: "The Geology of the Mokonui Subdivision." *Bull. No. 6 (N.S.), N.Z. Geol. Surv.*, 1908, p. 33.

The conformity that seems to exist between the Awamoko schists and the Kurow altered rocks may represent the actual relationship of these two systems. And stratigraphical conformity may exist between the Maitai and Mount St. Mary formations; but it seems inconceivable, in the light of the established relationship of the Lower and Upper Palæozoic systems of Europe and America, that there should be in New Zealand a continuous stratigraphical succession from the older or middle Palæozoic to the Jurassic.

The apparent stratigraphical conformity of the Kurow phyllites and the overlying Maitaian rocks may have arisen from persistent axial folding. The axial folding of the ancient Awamoko chain followed a north-west-south-east course. From what we know of mountain-building in the Cainozoic, with its persistent folding along defined axes, from the Eocene to the Pliocene, it does not seem difficult to conceive a revival of the Awamokoan folding in the Mesozoic of such magnitude as to involve the sediments of that era in folds running parallel with the pre-Permian folds, thereby giving an appearance of conformity which is in reality deceptive. As a matter of fact, the Upper Palæozoic and Mesozoic rocks, like the Awamokoan on which they rest, are bent in great north-west-south-east folds; but whether the whole of the Palæozoic and Mesozoic material formed one continuous succession, and were bent into the north-west-south-east folds at one period of crustal movement or formed two great unconformable systems folded along the same axis, but at different periods, is a problem that cannot be solved till more data are gathered in the field. In the absence of palæontological evidence it would be futile to stress the apparent stratigraphical conformity of the Kakanuian and Maitaian, due to parallelism of strike.

From the Permo-Carboniferous to the close of the Jurassic, deposition was continuous on a steadily sinking sea-floor on the present site of the Kakanui and Kurow chains. The increasing coarseness of the sediments in the upper portion of the succession tends to show that the land which provided the sediments was gradually rising. Of the situation and size of this land little or nothing is known. That it possessed continental dimensions is proved by the occurrence of Mesozoic rocks from one end of New Zealand to the other, throughout a length of a thousand miles. A study of the sediments does not help us greatly. The rapidly alternating argillites and sandstones, with associated bands of conglomerate, show us that the sediments were laid down in shallow water. The coarse conglomerates in the Trias of the King-country, Kawhia, East Cape, Nelson, and Southland are composed mainly of granite, gneiss, and other crystalline rocks. Here we have trustworthy evidence that the Palæozoic land, wherever it lay, was in some part composed of a complex of crystalline rocks, and continued to exist till the Middle Mesozoic.

Hutton held the view that the pre-Permian continental land lay to the west of New Zealand. Hector was of the same mind, and surmised that this elusive land was connected with the mythical Gondwanaland from which the Mesozoic sediments of India were thought to have been shed. There is little evidence in favour of the western site, and as little against it; and till more is known of the geological structure of the Antarctic continent we cannot hope to get nearer the truth.

The biological evidence, though scanty, would seem to favour the view that a greater New Zealand existed in Early Mesozoic time, connected with the Mesozoic land-masses of the Northern Hemisphere.

The tuatara (*Sphenodon punctatum*) of New Zealand belongs to a type of lizard that existed over a great part of the earth's surface as far back as the Triassic period. The New Zealand form of this archaic type is the only survival. The remainder have disappeared, or by a slow process of evolution have changed into other forms, suited to a new environment. *Sphenodon* is a reptile which lived on land, and

laid its eggs there. Hence its migration to this southern land could have been possible only by means of a land connection between this and the Triassic land of the Northern Hemisphere.

The survival of the *Sphenodon* family in New Zealand points to the severance of the southern land in the Middle Mesozoic. And the persistence of the type, without change, in the æons of time that have elapsed since the severance, suggests to us the absence of competitors and the prevalence of the same general climatic conditions.

Towards the close of the Jurassic period there travelled across New Zealand a series of mountain-forming crustal folds, all running in a north-west-south-east direction. Among the remains of this movement are the worn-down and truncated Hauraki chain in Auckland; the Kaimanawa chain in north Wellington; the Wairau chain between Nelson and Marlborough, of which the Richmond Hills are the forefold; and the Kurow-Kakanui Mountains of North Otago, now the subject of discussion. The evidence of this Late Mesozoic north-west-south-east folding has also been recognized in North Westland, and discussed by Morgan.* The north-west-south-east folding was antecedent to and independent of the north-east-south-west folding which built up the present axial chains of both Islands of the Dominion.

The wide hiatus that exists between the Jurassic and the Oamaruan would indicate that the newly formed Kurow-Kakanui chain remained above sea-level well into the Cainozoic; and the absence of rocks of Cretaceous or Eocene age on its present borders would lead us to conclude that it attained such a height that the waste produced by the denudation of its surface was discharged along the shores of a strand far to the eastward of the existing shore-line of North Otago.

At the close of the Eocene there was a general sinking of the land, but the submergence was not complete. On the diminished flanks of the Kakanui Mountains there was spread a sheet of quartzose sand and gravel that filled up the inequalities of the surface, and prepared a stretch of low-lying land along the eastern shores on which a dense jungle vegetation flourished for some time, or long enough to permit a thick deposit of decaying peaty matter to accumulate. The forest vegetation which at this time clothed the slopes of the mountains and maritime flats included the evergreen oak, beech, laurel, myrtle, and many pines. The period of vegetable growth on the flats recently reclaimed from the sea probably represented an interval when the downward movement of the land was arrested.

After a time the subsidence was renewed, and soon the maritime forests were inundated and destroyed. The denudation of the quartzose rocks, so strongly represented in the Kakanui and Kurow mountains, provided a pile of quartzose sands and gravels, beneath which the destroyed forest was buried in places to a depth of 300 ft. There is no evidence to show that these sediments were transported and spread out on the Miocene strand by a dominating trunk river. The small uniform size of the material might be taken to indicate that they were formed by a number of small streams draining the eastern slopes of the mountains; but this is not quite certain. The quartz folia in the mica-schists and the quartz layers in the claystone-quartz formation are always thin, rarely exceeding 4 in. in thickness. The quartz itself is much shattered, and when the interfoliated softer rock was removed it would break up into small fragments without much resistance.

The subsidence still continued, and the land subject to denudation correspondingly diminished in extent. Over the fluvio-marine Ngaparan sediments were spread marine sands and clays, the former micaceous, as would be expected from the denudation of

* P. G. Morgan: "The Geology of the Mokonui Subdivision, North Westland." *Bull. No. 6 (N.S.),* 1908, p. 34.

the mica-schists and phyllites providing the quartzose material of the sands. The fossil contents of these sediments tell us that the seas of this period swarmed with molluscan life, with cetaceans, with sharks, and other fishes, &c. The molluscan and other marine life of this time indicates the prevalence of climatic conditions that were not much different from those of the warm temperate zones of the present day.

At the close of the Ngaparan there began, many miles seaward of the Miocene strand, a series of submarine volcanic outbursts that continued with intermittent periods of rest up till the middle of the Ototaran stage. Two main periods of activity may be recognized—namely, one that began at the close of the Ngaparan and continued with two short intervals of rest up to the beginning of the Ototaran; and one that produced the tuffs and lavas associated with the Oamaru limestone. In the neighbourhood of Oamaru the activity continued till the close of the deposition of the Hutchinson Quarry limestone; and in this area the Oamaru limestone is represented by tuffs and basalt-flows. The irregular lenses of ash in the Hutchinson Quarry limestone would indicate that the expiring outbursts were feeble and intermittent.

The first outbursts were perhaps the most intense, prolonged, and far-reaching in their effects. The fragmentary material was projected as far south as the Kakanui, as far west as Elderslie, and as far to the north-west as Papakaio. With the exception of two short intervals of rest, the outbursts continued throughout the whole of the Waiarekan stage. The periods of rest are marked by two calcareous horizons and a slight discordance of stratification in the Cape Wanbrow section, and by two horizons of diatomaceous earth in the tuffs of the Waiareka Valley and Papakaio district. And while volcanic ejectamenta were being piled up around Oamaru, normal marine sediments were accumulating on the sea-floor along the ancient Kakanui strand.

In a few places floods of basaltic lava poured over the sea-floor, and there became intercalated with the volcanic ash and muds.

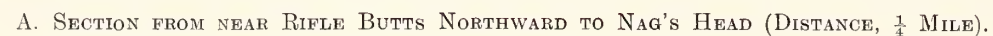
The character of the sediments and the contained life show that the materials were deposited in shallow water. The slow sinking of the land that began with the Miocene still continued.

At the close of the Waiarekan there was a complete cessation of volcanic activity for a considerable time; and in the clear warm waters of the Oamaru sea reef-building Polyzoa established themselves on the newly formed submarine tuff platform, and by their growth formed the Ototaran limestones. Here we find that it was not the subsidence of a dry-land area, as postulated by the Darwinian hypothesis, but the rapid piling-up of a volcanic platform on the sea-floor that led to the formation of this off-shore fringing coral reef. Building upward, and not subsidence, was the originating factor.

Towards the close of the Ototaran stage there was a revival of volcanic activity, during which much ash was ejected, thickest and coarsest near Kakanui Heads, but thinning out and becoming finer in texture towards the west, eventually disappearing near Weston. The ash destroyed the reef-builders, and buried their remains under a thick sheet of volcanic ejecta that, as stated above, tapered out to nothing when passing away from the centre of activity.

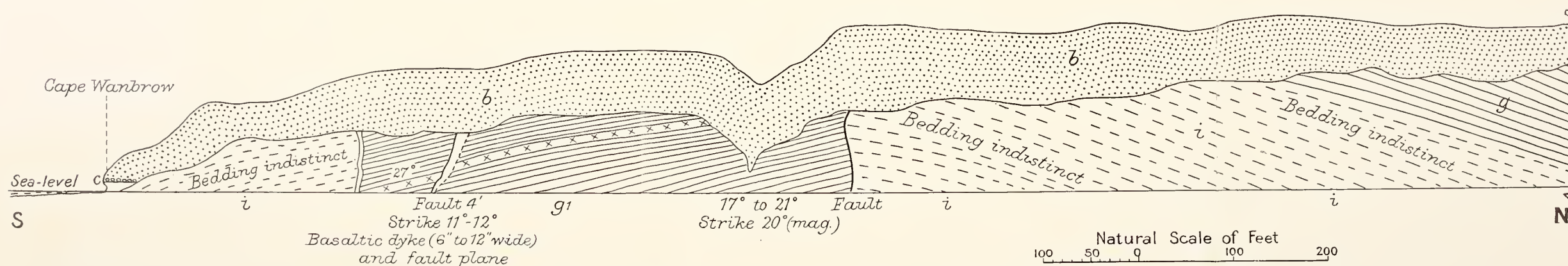
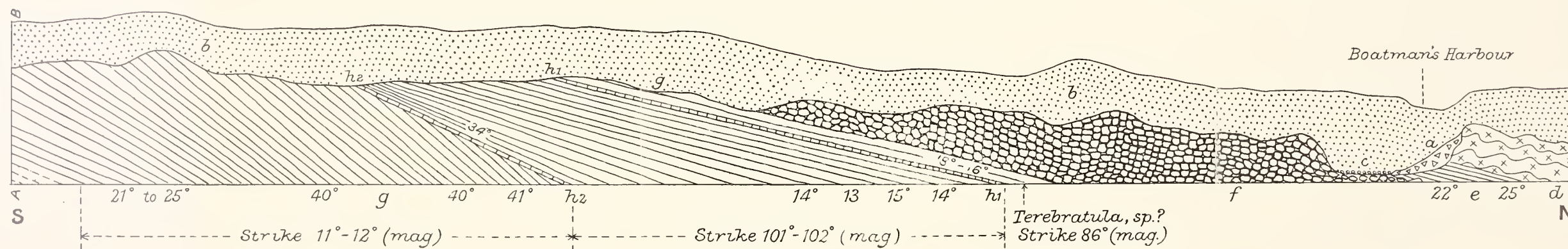
Then followed a period of quietude, during which the Polyzoa established themselves on the newly ejected volcanic ash and muds. Beyond the limits covered by the volcanic material the reef-building had continued uninterruptedly; hence in the Weston area we get an unbroken sheet of Ototara limestone, while east of that this limestone is split into two unequal portions by a wedge of tuffs that rapidly thickens as we proceed towards Kakanui.

The inter-Ototaran tuffs contain a rich and varied molluscan fauna, from which we gather that they were not produced by a single violent outburst, but were ejected as a



Waiarekan.

- r. Coars^e calcareous tuff, fossiliferous; 4 in.—12 in.
- s. Yellowish-brown calcareous coralline tuffs; 42 ft.
- t. Band of calcareous pebbly grit with *Liothyrella*, *Oamarutica*, *Venericardia*, &c.; 0 in.—12 in.
- u. Thin-bedded tufaceous sands and clays; 20 ft.
- v. Hard bluish-green calcareous tuffs, glauconitic, with small fragments of vesicular basalt, fossiliferous; 2 ft.—6 ft.
- w. Well-bedded tuffs with blocks of vesicular basalt, in places glauconitic and calcareous, showing current-bedding; 70 ft.
- x. Wedge of friction breccia on fault-plane.



B. MEASURED SECTION OF WAIAREKAN TUFFS AND BASALTS FROM BOATMAN'S HARBOUR TO CAPE WANBROW (DISTANCE, $\frac{2}{3}$ MILE).

- | | | |
|---------------------------------------|--|---|
| <i>a.</i> Slope deposit. | <i>e.</i> Fossiliferous tuffs, sandstones, clays, &c. | <i>h</i> ¹ & <i>h</i> ² . Beds of hard limestone, 3 in.-12 in. thick, brecciated with |
| <i>b.</i> Pleistocene silts. | <i>f.</i> Basaltic pillow-lava. | large angular pieces of basalt. |
| <i>c.</i> Raised beach; 12 ft. | <i>g.</i> Well-bedded tuffs, buff and greenish-brown. | <i>i.</i> Bluish-green tuffs, bedding indistinct. |
| <i>d.</i> Brecciated tachylitic lava. | <i>g</i> ¹ . Well-bedded tuffs, lying between two faults. | |

number of small intermittent showers that slowly settled on the floor of the surrounding sea, so slowly that the contemporary marine life was not destroyed.

It is noteworthy that during the Ototaran period many basaltic dykes intruded the Waiarekan tuffs at Cape Wanbrow and in the Waiareka Valley. At Maheno some dykes have penetrated far into the Oamaru limestone, in the form of sheets or sills. The intrusion was not confined to the volcanic zone; dykes are found to have invaded the quartzose Ngaparan coal-measures and the overlying sandstones of Waiarekan age. The intrusion of these dykes appears to have been contemporaneous with the second period of volcanic activity which produced the inter-Ototaran tuffs at Deborah and Kakanui.

At the close of the Ototaran stage the persistent downward movement of the Ngaparan, Waiarekan, and Ototaran times was arrested, and there began an upward movement of short duration. This uplift, though only a minor oscillation in the general sinking of the land and sea-floor, led to the invasion of the "coral reefs" by myriads of brachiopods and many molluscs. These brachiopods and molluscs, by the infiltration of calcareous matter, afterwards formed the hard bed of limestone variously known as the Hutchinson Quarry, Deborah, Flat Top Hill, or Kakanui limestone. During this period the neighbouring sea was inhabited by the toothed cetacean, *Kekenodon onamata* Hector; by the gigantic shark, *Carcharodon megalodon* Agassiz; a ray, *Myliobatis plicatilis* Davis; the large nautilus, *Aturia australis* McCoy; and a great variety of Polyzoa and Foraminifera, together with many species of brachiopods and pectens; while the shores were frequented by a giant penguin, *Palæudyptes antarcticus* Huxley.

Westward of the volcanic area the Deborah limestone lies hard on the upper surface of the Oamaru limestone. During this period of uplift there was laid down on the surface of the Deborah limestone a thin sheet of marine gravel that in the neighbourhood of Oamaru is mainly composed of basaltic pebbles. Among the most conspicuous fossils in this gravel are a thick-shelled oyster, *Ostrea wuellerstorfi* Zittel; the teeth of the large shark, *Carcharodon megalodon* Agassiz; and a large brachiopod, *Terebratella* sp. cf. *T. neozealandica* von Ihering.

The character of the constituent pebbles proves that some portion of the recently ejected volcanic material now formed a dry land surface, subject to denudation, or perhaps low islands or reefs just awash, and hence subject to the pounding action of the ocean-waves and erosion of coastal currents. This bed of gravel, now compacted into a conglomerate, is a thin but persistent member of the succession, and can be traced westwards as far as the Devil's Bridge. At All Day Bay it rests on a corroded surface of the Kakanui limestone. The stratigraphical unconformity between the Ototaran and Hutchinsonian, though well marked at All Day Bay, is indistinguishable outside the Oamaru district. It is merely a local discordance, in some way connected with the contemporaneous volcanic activity in this neighbourhood.

About the middle of the Hutchinsonian, subsidence again came into evidence, the downward movement being accompanied by the deposition of sandy material coated with glauconite, and in places crowded with brachiopods, pectens, and the distinctive coral *Isis dactyla* T.-Woods. The sharp line of demarcation between the conglomerate and the greensands indicates that a complete change in the local conditions of deposition took place in a relatively short period of time, the change probably arising from the rapid submergence of the volcanic islands that furnished the material forming the conglomerate.

On the still sinking sea-floor were now laid down glauconitic sandy beds that were followed by shelly sands, blue sandy clays, and muds. The glauconitic sandy beds are usually calcareous; they form the uppermost member of the Hutchinsonian, while the overlying shelly sands and clays comprise the Awamoan.

With the exception of one or two minor oscillations, a general subsidence prevailed throughout the whole of the Miocene. As the subsidence progressed the sea encroached more and more on the dry land. As a result of this landward transgression from east to west, the succession of deposits at places far to the westward cannot be coeval with that of places farther eastward, where deposition began at an earlier stage. While the conditions of deposition were marine at Oamaru, those at Wharekuri may have been terrestrial or fluvio-marine. Hence the succession of the Oamaruan at Wharekuri may be somewhat later in date than that at Oamaru.

As soon as the sea invaded the inland places now occupied by Middle Cainozoic beds the marine life in the continuous sea was everywhere the same in the same bathymetrical zones. If marine deposition began at Wharekuri during the Ototaran stage of Oamaru we should expect the molluscan life in the Wharekuri marine deposits overlying the quartzose lignitic measures at that place to be closely related to, though not identical with, the molluscan life of the inter-Ototaran tuffs at Deborah and Kakanui: the palæontological evidence supports this view—that is, the molluscan fauna of the Wharekuri marine beds, as will be shown in the sequel, is more nearly related to that of the Kakanui inter-Ototaran tuffs than to the fauna of the Black Point marine beds, which also follow the lignitic measures. The problem becomes clear only when we remember that the Black Point marine beds (Bortonian) were deposited before the sea had reached the Wharekuri area.

It should be noted that the Oamaru stone represents a fossil polyzoan reef that flourished a few miles off the Miocene strand. It is a purely local deposit, found only in the neighbourhood of Oamaru, and nowhere else in New Zealand; but fortunately for us the contemporaneous molluscan life has been preserved in the volcanic tuffs intercalated with it at Kakanui and other places.

After the deposition of the Awamoan there began in the Early Pliocene a general uplift that affected not only the Oamaru area, but the greater portion of the South Island. The land rose to such a height that the newly formed Middle Cainozoic sediments began to be worn away by subaerial erosion.

Along the east coast of Otago and South Canterbury the Oamaruan strata lie at or near sea-level; but inland they gradually rise till they attain a height of 1,000 ft. above the sea. The inference to be drawn from this is that the uplift was not uniform, but a differential tilting that was more rapid along the main axial chain than elsewhere.

In the Nelson terrain the Oamaruan rises from sea-level to a height of 3,000 ft. on the flanks of the north-east-south-west axial divide, and is everywhere marginal to it. Here we have evidence of more acute differential uplift than in Otago. Further, we gather that the Middle Cainozoic deposits of New Zealand were laid down when the existing alpine chain was partially submerged. The portion of the chain that stood above sea-level during the Miocene evidently possessed great length and little breadth; but its mass was, nevertheless, sufficient to produce the detritus of the Miocene deposits.

The differential Pliocene uplift affected the whole of the South Island, and subjected the older folded rocks to tensional stresses that were relieved by the formation of powerful axial faults. Between these faults the covering sheet of Middle Cainozoic deposits was uplifted in narrow step-like blocks that increase in height going towards the main divide. In some places patches of the Tertiaries, usually highly tilted and sharply folded, have been preserved in trough-like basins that are bounded by faults and walled in by blocks of the older rocks, from the surface of which the Oamaruan deposits have been removed by denudation. The last emergence of the alpine chain of the South Island probably took place in the Early Pliocene. The

submergence of this great folded chain which preceded the Pliocene emergence led to the deposition of the great Oamaruan succession.

The north-east-south-west folded axial chain of the North Island was also submerged during the Oamaruan, but the submergence lasted longer than in the South Island. This we learn from the circumstance that a sheet of older Pliocene strata rises high on the flanks of the Ruahine and Kaimanawa ranges. Here also we have a trustworthy measure of the extent of the uplift that took place in later Pliocene times. The Miocene deposits of the South Island were uplifted in blocks by great parallel faults, whereas the older Pliocene strata of western Wellington rise from sea-level at the Wanganui Bight as a gently sloping plain that in a distance of fifty miles reaches a height of 3,000 ft. on the southern flanks of Mount Ruapehu, and of 3,600 ft. on the slopes of the Kaimanawa Mountains. This broad sloping plain is bounded on the east by the Pohangina fault, and on the west by the Waimarino fault. Clearly, the differential uplift of the older Pliocene strata in this area is due to crustal tilting accompanied by faulting, the pivot of the movement being situated in the Wanganui Bight.

Similarly, the older Pliocene strata of Hawke's Bay rise gradually going westward till they reach a height of 3,600 ft. on the flanks of the Ruahine chain. And since the west side of this chain is bounded by the powerful Pohangina fault, we have good reason to conclude that the great axial divide of the North Island is also a tilted block.

The dry land which emerged from the sea during the Early Pliocene in the South Island and later Pliocene in the North Island gave New Zealand its present outline and configuration. Little or no change has taken place since the Pliocene, except that caused by the building of coastal plains or the piling-up of the products of volcanic activity, the latter for the most part in the North Island. The uplift has been maintained up to the present day, though there have been various minor oscillations, prominently those arising from volcanic activity or seismic causes.

There is good reason to believe that it was in the early stages of the Pliocene uplift that the existing river-systems of the South Island began to be developed, and the development kept pace with the upward movement. As the emergence progressed the alpine rivers cut down the present narrow transverse valleys by which they reach the sea.

Some time during the Early Pliocene the newly raised Miocene strata at Oamaru were gently folded along their seaward margin, the folding producing the Waiareka anticline and Awamoa syncline. The cause of this folding and tilting is obscure; but if we may judge from its local character it may be a result of crustal settlement around the scene of the Miocene volcanic activity.

For some time the uplifted and folded Oamaruan strata were subject to sub-aerial denudation; and then upon their denuded surface the Waitaki River spread a thick sheet of sand and gravel, composed of material derived from the erosion of the older rocks along its course. Soon after the deposition of these gravels there was a clearly defined uplift of the land, which raised the ancient flood-plain to a vertical height of about 300 ft. above sea-level, thereby forming what is now the Oamaru tableland. The progress of this uplift was marked by two periods of rest, during which the sea cut the rocky headlands around Cape Wanbrow into gently sloping platforms. The older of these planes of marine erosion now stands at a height of 42 ft. above sea-level. The younger or lower, which is naturally the better preserved, forms a well-marked feature on the rock-bound coast near Oamaru and at Kakanui. It lies 12 ft. above high-water mark.

While the uplift of the Oamaru tableland was in progress the Waitaki River excavated the lower end of its course in the gravels it had previously laid down, and in this way formed the Papakaio Plain, which is merely the present valley-floor. This work of excavation was probably completed in the Early Pleistocene. The Pliocene uplift may have been in part responsible for the widespread Pleistocene glaciation of the South Island, but to what extent is unknown.

The deposition of yellow silts closes the last chapter of the geological history of Oamaru. These silts extend along the coast from Timaru to Moeraki, and occur as an irregular sheet that overspreads all the older formations, including even the tableland gravels. They are thickest on the sea-front of Cape Wanbrow and seaward face of the tableland behind Oamaru. Their mode of occurrence and distribution would indicate that they are fine sediments of glacial origin cast upon the Pleistocene strand, and carried inland by the prevailing easterly winds.

CHAPTER II.

PALÆOZOIC ROCKS.

Distribution	Page	Arrangement	Page
Character	21	Economic Minerals	22

DISTRIBUTION.

THE Palæozoic rocks form a low truncated flat-topped ridge that extends from near Peebles to Black Point. A small isolated patch crops out in the bed of a deep gorge on the south-east side of Big Hill, and there is reason to believe that the basement beds of the Oamaruan coal-measures everywhere in this district rest on Palæozoic rocks. The Palæozoic rocks are flanked on the south, west, and north by the conglomerates of the coal-measures, and at one time they were probably completely covered by Tertiary deposits.

CHARACTER.

The Palæozoic rocks are mica-schists that in places pass into typical phyllite. The mica-schist is a slate-grey rock laminated with quartz. When viewed in mass it presents a dark-russet appearance on weathered surfaces. The quartz and mica laminæ are often corrugated or wavy. When examined in thin slice the rock is seen to consist almost entirely of quartz and mica, arranged in thin irregular layers. A plagioclase feldspar, probably albite, is often present, as well as rutile in long thin needle-shaped crystals. The mica is sericitic, white in colour, and probably muscovite. The mica and quartz laminæ vary considerably in thickness: in places they are as thin as tissue paper, in others 1 in. or more in thickness. In some places the quartz laminæ are thicker than the mica laminæ, and in other places the converse is true. With a rock so variable in constitution it is impossible to select a single example that is truly representative of the whole.

As shown by the following analysis, the composition of this mica-schist does not differ greatly from that of the less altered schists of Alexandra, Central Otago:—

Silica (SiO_2)	..	..	..	..	57.42
Alumina (Al_2O_3)	..	..	..	..	20.16
Ferric oxide (Fe_2O_3)	..	..	..	..	3.84
Ferrous oxide (FeO)	..	..	..	..	2.76
Manganous oxide (MnO)	..	..	..	..	0.19
Chromic oxide (Cr_2O_3)	..	..	..	..	Nil
Lime (CaO)	..	..	..	..	4.06
Magnesia (MgO)	..	..	..	..	2.14
Titanium oxide (TiO_2)	..	..	..	..	0.61
Potassium oxide (K_2O)	..	..	..	..	3.16
Sodium oxide (Na_2O)	..	..	..	..	2.01
Sulphuric anhydride (SO_3)	..	..	..	..	0.12
Carbon dioxide (CO_2)	..	..	..	..	0.30
Water lost below 100°C .	..	..	..	..	0.41
Water lost above 100°C .	..	..	..	..	2.54

The phyllites are interstratified with the mica-schist. The typical phyllite varies from light to dark grey, and possesses a characteristic silky lustre along the planes of stratification. Frequently the rock is rusty along the folia, owing to the oxidation of the pyrites disseminated along the foliation-planes.

Microscopically examined the rock is seen to consist essentially of minute scales of white sericitic mica and quartz, with sometimes a little chlorite.

The mica-schists and phyllites appear to be altered sediments; and in both the foliation-planes are parallel to the original planes of stratification.

ARRANGEMENT.

Good sections of the mica-schists are seen in the gorge of Awamoko Stream, in a deep gulch near Georgetown, and in the road-cuttings of the Georgetown Ngapara Road. The strike is everywhere about north-west-south-east, and the direction of dip south-west. The angle of dip of the lowermost rocks, as seen along the Waitaki front, varies from 55° to 65° ; but in going south-westward the angle of dip becomes steeper and steeper, till at the point where the uppermost rocks disappear below the younger deposits, as seen at the upper end of the Awamoko Gorge, the dip is 84° . If the average angle of dip is taken at 72° , the thickness of mica-schist and phyllite exposed in the Awamoko section cannot be less than 9,000 ft.

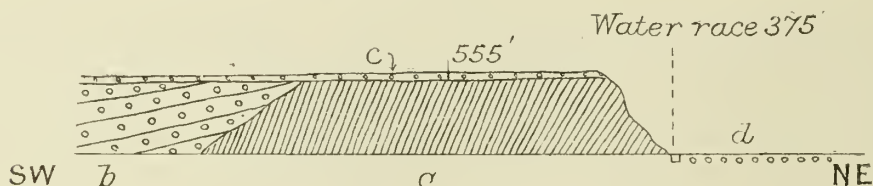


FIG. 1.—SECTION ALONG AWAMOKO GORGE.

(Distance, $1\frac{1}{4}$ miles.)

a. Mica-schist and phyllite.
b. Ngaparan coal-measures.

c. High-level Waitaki gravels.
d. River-valley gravels.

There is nothing to indicate the age of these rocks except the fact that they underlie the great succession of argillites and semi-metamorphic greywackes that form the Kurow Mountains and that, in turn, lie below the fossiliferous Triassic or Permo-Triassic rocks at Mount St. Mary.

ECONOMIC MINERALS.

Small amounts of gold have been washed from the gravels in the Awamoko Gorge, but the limited extent of the gravelly alluvium that has survived the scouring effects of the stream when swollen by torrential rains precludes the possibility of a payable discovery being made on the course of this stream, which for the greater portion of its length is a steep rock-bound gorge.

CHAPTER III.

THE MIDDLE CAINOZOIC (OAMARUIAN SYSTEM).

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Fauna and Flora	23	Tabular Statement of Oamaruan Strata	28
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DISTRIBUTION.

THE Oamarnian extends from the sea westward to the foot of the Kakanni Range; and, with the exception of small patches of the Palæozoic basement rocks exposed by denudation in the Ngapara and Livingstone districts and the Awamoko mica-schist ridge in the Waitaki Valley, it occupies the whole of the terrain lying between the Kakanui and Waitaki rivers.

CHARACTER OF ROCKS.

The lowermost strata consist of fluviatile gravels, sands, clays, and lignite. These are followed by marine sands, clays, and calcareous deposits that in the coastal area are intercalated with the products of contemporaneous volcanic activity.

The coarser drifts of the fluviatile series are usually consolidated into hard limonitic conglomerates, while the sandy beds and finer quartzose drifts are mostly loose and incoherent.

In the marine series the clays are usually soft and often interbedded with hard flaggy masses or isolated lenses of more sandy material, as a rule crowded with fossil molluscs. The marine sandy beds are frequently soft, but seldom incoherent except where highly glauconitic. Mostly they are calcareous, and hard enough to form steep faces where exposed on the banks of deep streams. The limestone members are soft, or very hard and compact.

CONDITIONS OF DEPOSITION.

The fluviatile deposits were laid down along the strand of the old Miocene land on a slowly sinking sea-floor. The subsidence persisted till near the close of the Miocene, and during its progress the fluviatile deposits became buried beneath a great thickness of marine material. The marine clays and sandy beds are detrital, while the limestones are largely the work of reef-building Polyzoa.

The volcanic activity which began at the close of the fluviatile period was submarine, intermittent, and mainly of the explosive type. The ejected fragmentary material consisted of ash that ranged from the finest dust to the coarsest breccias. Effusions of lavas were rare, and when they did take place seldom reached far from the point of emission.

In the Oamaru and Kakanui areas the normal marine deposits are intercalated with ash-beds and lavas; but the products of the eruptions do not extend far from the centres of activity. Doubtless the violence of the outbursts was greatly diminished by the pressure of the overlying sheet of water.

FAUNA AND FLORA.

At the time of the deposition of the Oamarnian sediments the shallow waters around the coast teemed with a rich and varied assemblage of molluscan life. Many

of the molluscs grew to a great size, which may be taken to indicate the existence of a plentiful food-supply and the prevalence of a warm temperate climate in the New Zealand Miocene. Prominent among the shell-fish which flourished in these genial seas were,—

Ostrea wuellerstorfi Zitt.

Ostrea nelsoniana Zitt.

Pecten beethami Hutt.

Pecten hutchinsoni Hutt.

Pecten huttoni (Park).

Lima levigata Hutt.

Lima colorata Hutt.

Cucullaea alta Sow.

Cardium spatiosum Hutt.

Crassatellites amplus (Zitt.).

Dosinia magna Hutt.

Dentalium solidum Hutt.

Turritella cavershamensis Harris.

Polinices ovatus (Hutt.).

Brachiopods first appear in the Upper Waiarekan, reach their maximum development towards the close of the Oamaruan, and almost disappear at the close of the Hutchinsonian.

The deeper waters were inhabited by a great variety of Polyzoa, Foraminifera, diatoms, sponges, and radiolarians. In these and the neighbouring seas there lived a zeuglodon whale (*Kekenodon onamata* Hector), and a giant penguin related to an existing Antarctic type (*Palæudyptes antarcticus* Huxley). Fishes were numerous, and included the gigantic *Carcharodon megalodon* Agassiz, and a great ray (*Myliobatis plicatilis* Davis). The cephalopods were represented by *Aturia australis* McCoy, a large nautilus which also inhabited the Australian Miocene seas.

Of the vegetation that clothed the maritime slopes of the Miocene land only the scantiest information is available. This arises not so much from the poverty of the vegetation as from the character of the deposits that form the coal-measures. These consist mainly of coarse conglomerates or loose quartzose gravels and sands. Muds or shales in which leaves and other vegetable-remains might have been preserved are almost entirely absent. Within the Oamaru terrain no recognizable plant-remains were found, but in the coal-shales at Livingstone Railway Tunnel there occur a few impressions of dicotyledonous leaves and some palm-nuts. Elsewhere in the Oamaruan brown-coal measures there have been identified the leaves of the beech, myrtle, *Aralia*, *Dammara*, *Podocarpus*, *Dacrydium*, palms, and numerous ferns—all showing a generic relationship to the existing flora. If the identifications are correct we have in this relationship a proof that the New Zealand mountains have not been wholly submerged since the Cretaceous period.

In the brown coal are sometimes found trunks and limbs of forest-trees, and nests of a resin resembling kauri-resin, or so-called kauri-gum.

SUBDIVISION OF THE OAMARUAN.

In 1876 McKay* divided the Middle Cainozoic strata of the Oamaru district into five groups of beds. They are, in descending order,—

- (1.) Awamoia beds.
- (2.) Hutchinson Quarry beds.
- (3.) Ototara stone.
- (4.) Waiareka tuffs.
- (5.) Quartzose coal-measures.

The correctness of the succession as determined by McKay has been confirmed by the present detailed survey.

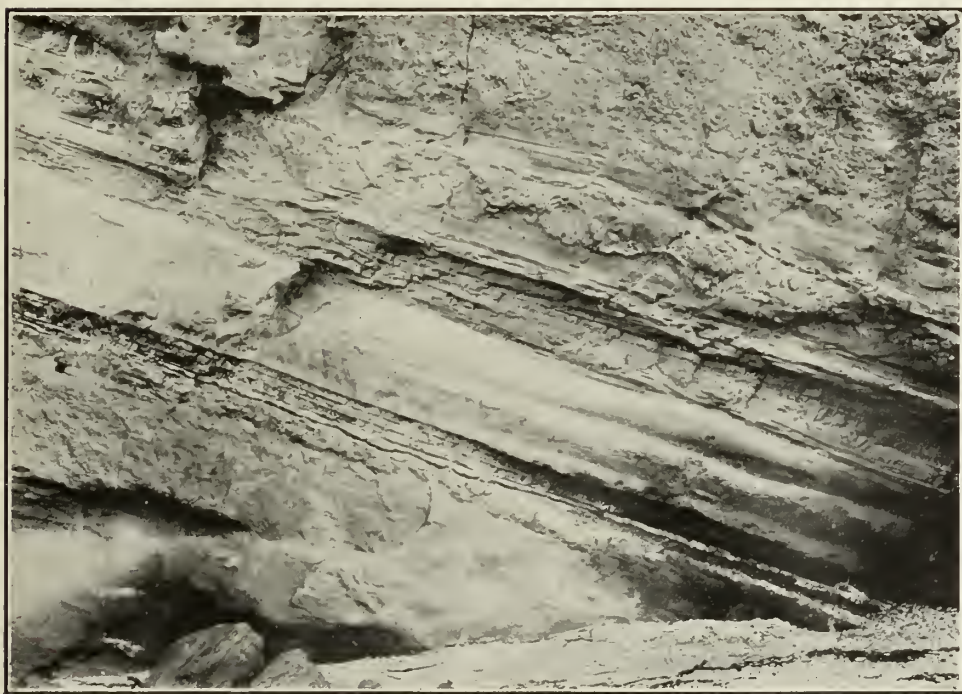
* A. McKay: 'Report on Oamaru and Waitaki Districts.' *Rep. Geol. Explor. during 1876-77*, No. 10. 1877, pp. 41 66: 2 figs.

PLATE III.



A. C. Gifford, photo]

A. BASALTIC DYKE NEAR CAPE WANBROW.



A. C. Gifford, photo.]

B. FINE TUFFS, WELL-BEDDED, NEAR CAPE WANBROW.

STAGE-NAMES.

For a classification to be a trustworthy standard of reference it is an essential requirement that the subdivision shall be made in a district where the component subdivisions are in such intimate association that their relationship to one another can never be in doubt. It is certain that nowhere in New Zealand are the Middle Cainozoic rocks so fully represented as in North Otago, nowhere are they so little disturbed and their stratigraphical relationships so clear, and nowhere do they contain so many fossiliferous horizons.

In his paper "On Stage Names applicable to the Divisions of the Tertiary in New Zealand" Thomson* suggests the use of stage-names for the subdivisions of the Oamaruan System. He takes the Middle Cainozoic rocks as developed in North Otago as the typical succession, and adopts the adjectival form of McKay's place-names of 1876 for the different groups of marine beds. For the basement quartzose coal-measures group he proposes the stage-name "Ngaparan." Thomson's stage-names are,—

- (1.) Awamoan.
- (2.) Hutchinsonian.
- (3.) Ototaran.
- (4.) Waiarekan.
- (5.) Ngaparan.

The author's place-name "Kaikorai," first used by him in 1910† for the Oamaruan quartzose coal-measures of Kaikorai Valley, Fernhill, and Green Island, near Dunedin, should, in the strict order of things, take priority of Thomson's stage-name "Ngaparan." Arising from the absence of fossiliferous horizons in the Middle Cainozoic near Dunedin, there must always remain a doubt as to the relationship of the Kaikorai to the Ngapara quartzose coal-measures. They may or may not be contemporaneous. The relationship of the Ngaparan to the Waiarekan is quite clear in North Otago, whereas the relationship of the Kaikorai beds of Dunedin to the Waiarekan of Oamaru is unknown. In these circumstances, in order to avoid the duplication of names and the confusion that might arise from the selection of a series of beds as typical, the relationship of which to the Waiarekan of Oamaru is incapable of proof, it seems inexpedient to revive the older name.

The five subdivisions of the Oamaruan recognized by the old Geological Survey under Sir James Hector and by Thomson were not expressly based on palæontological grounds, but on the close stratigraphical association of certain related groups of beds.

The palæontological evidence collected during the present survey shows that the Waiarekan consists of an upper and a lower horizon. The lower, as typically developed near Borton's,‡ contains the oldest marine fauna of the Oamaruan. This fauna is notable, since it marks the first encroachment of the sea on the lignitic strata. The Bortonian group contains many interesting forms, some of the genera being new to the New Zealand fauna.

The upper or true Waiarekan marks the advent of the brachiopods, which play so important a part in the Middle Oamaruan. It possesses an abundant molluscan fauna that is more nearly related to the inter-Ototaran than the Bortonian.

On palæontological grounds the Hutchinsonian might be divided into two sub-stages—the lower or true Hutchinsonian including the glauconitic greensands, the upper comprising the glauconitic calcareous sandstone that forms the Waitaki stone or Waitakian.

* J. A. Thomson: *Trans. N.Z. Inst.*, vol. xlviii, 1916, p. 28.

† James Park: *The Geology of New Zealand*, 1910, p. 108.

‡ Borton's is on the branch railway-line to Kurow, and is twenty-four miles from Oamaru. It is outside the area mapped in this bulletin.

When dealing with the subdivision of the Miocene we must ever keep in mind the fact that this period covers a relatively short space of time: hence great faunal differences as between the different members are not to be looked for. What we do find in passing upward from the lowermost marine horizon is a progressive increase in the number of living species. Apart from this, the molluscan faunas show a strong family resemblance throughout the whole of the Oamaruan.

There are several stratigraphical unconformities in the Miocene of Oamaru, but they are in every case local and intra-formational.

THE OAMARUAN SUCCESSION.

In the greater portion of the area covered by this bulletin the Middle Cainozoic succession is intercalated with the products of submarine volcanic activity, consisting mostly of fragmentary material. The centre or centres of activity were situated somewhere seaward of Oamaru and Kakanni. The volcanic energy expended itself in numerous small explosive outbursts, as a result of which a great thickness of well-bedded ash was in time piled on the slowly sinking sea-floor. On a few occasions there was an emission of basaltic lava which crept along the sea-floor in tongue-like sheets. The accumulation of the fragmentary material was so slow that the contemporary marine life was still able to inhabit the sea within the volcanic zone.

To the south and westward of the volcanic zone normal marine deposition continued without interruption. Thus it happens that in the Oamaru Survey District we have both the normal marine succession and the normal succession intercalated with tuffs and lavas. The volcanic activity piled up a considerable thickness of pyroclastic beds that in places formed marine shoals, thereby creating conditions that favoured the assemblage of a varied molluscan fauna. These favourable conditions did not always exist where the normal marine sediments were accumulating; hence we find that fossiliferous horizons of molluscan life are more numerous in the pyroclastic than the clastic succession—that is, where the grey glauconitic sandy beds underlying the Waitaki (or Ngapara) stone are replaced by the Oamaru stone from Tabletop Hill eastward to the sea.

In the narrow maritime strip lying between Deborah and Kakanui the Oamaru stone is itself intercalated with calcareous tuffs that contain a rich molluscan fauna.

The normal succession to the eastward and westward of a line running from Ngapara to Papakaio is as follows:—

	<i>Near Old Shore-line.</i>	<i>Eastward of Old Shore-line.</i>
Awamoan. . .	(a) Blue clays and sandy beds . . .	(a) Blue clays and sandy beds.
	(a) Glauconitic sandstone with hard calcareous layers (= Waitaki or Ngapara stone)	(a) Glauconitic sandstone with hard calcareous layers (Papakaio, Landon's Creek, Tabletop Hill).
Hutchinsonian . . .	(b) Glauconitic greensands, with many brachiopods	(b) Glauconitic greensands, with many brachiopods.
Ototaran . . .	(a) Grey glauconitic sandy beds . . .	(a) Deborah limestone.
	(a) Soft brown sandstones . . .	(b) Oamaru stone.
Waiarekan . . .	(b) Hard calcareous glauconitic sandstone bed (Bortonian)	(a) Thin-bedded marly clays.
		(b) Yellowish-brown sandstones with hard concretions.
Ngaparan . . .	(a) Quartzose sands, grits, and conglomerates with lignite	(a) Quartzose sands, grits, and conglomerates with lignite.

AGE OF THE OAMARUAN.

The fossils collected by the Hon. Walter Mantell in 1850 were examined by Professor Morris and Professor Rupert Jones, by whom the Ototara limestone was, with doubt, referred to the Cretaceous or Eocene period*; but it should be remembered that at this date the living fauna of the New Zealand coasts was imperfectly known.

* *Quart. Jour. Geol. Soc. Lond.*, vol. vi, 1850, p. 324.

In 1865 Sir James Hector placed the Moeraki Series below the Oamaru Series, and considered both to be Miocene. The volcanic tuffs and basalts he considered Pliocene.*

In 1869 Mr. C. Traill, after examining a collection of fossils he made at Awamoa, came to the conclusion that the Awamoa beds were Miocene.†

In 1870 Hector placed the Awamoa beds in his "Upper or Struthiolaria Series," and the Oamaru limestone, including the Hutchinson Quarry beds, in his Older or Ototara Series of "Tertiary" age.‡

In 1872 Captain Hutton referred the Ototara group to the Upper Eocene.§

In 1873,|| and again in 1875,¶ Hutton placed the Oamaru Formation in the Upper Eocene.

In December, 1876, and January, 1877, A. McKay examined the Oamaru district.** He maintained that the Hutchinson Quarry beds were unconformable to the Ototara limestone. The former he placed in the Upper Eocene and the latter in the Cretaceo-Tertiary. The Awamoa beds were referred to the Lower Miocene.

In 1882 Sir James Hector stated that the Ototara limestone is separated from the Hutchinson Quarry beds by a series of volcanic rocks which he thought belonged to the Cretaceo-Tertiary period.††

In 1882 McKay again visited the Oamaru district, and in his report refers the Oamaru Series to the Upper Eocene.‡‡ On this as on former occasions he does not recognize any stratigraphical break between the Hutchinson Quarry and Awamoa beds.

In November, 1885, Hutton again examined the Oamaru district.§§ He concluded that there was no stratigraphical break between the Cretaceo-Tertiary and the Upper Eocene formation of the Geological Survey.|||

In 1891, as a result of their examination of the sponge-remains in the diatomaceous earth-deposits in the Waiarekan, G. J. Hinde and W. M. Holmes¶¶ placed the deposits in the Upper Eocene or Oligocene.

In 1903 and 1904 the author examined the Oamaruan in North Otago and South Canterbury, and made considerable collections of fossils, which were submitted to Captain Hutton for identification. The proportion of living molluscs was found to range from 20 per cent. in the lower horizon to 30 per cent. in the upper. The high proportion of living forms, and the probability that exhaustive collecting would increase rather than decrease that proportion, led the author to refer the whole of the Oamaruan System to the Miocene period.***

In his *Geology of New Zealand*, 1910,††† the author discusses the age of the Oamaruan. He restates his views of 1905, and once more refers the system to the Miocene period.

In 1910 F. Chapman, in a discussion on the relationship of the Oamaruan to the Miocene of Australia, South America, and Europe, considers the New Zealand Oamaruan to be of Miocene age.††††

* *Quart. Jour. Geol. Soc. Lond.*, vol. xxi, 1865, p. 128; with section.

† *Trans. N.Z. Inst.*, vol. ii, 1870, p. 167.

‡ *Cat. Colonial Museum*, 1870, pp. 178, 179, 189.

§ *Rep. Geol. Explor. during 1871-72*, No. 7, 1872, p. 184.

|| *Cat. Tert. Mollusca and Echinodermata of N.Z.*, 1873.

¶ *Geology of Otago*, 1875, p. 21.

** *Rep. Geol. Explor. during 1876-77*, No. 10, 1877, pp. 48-66; with map.

†† *Rep. Geol. Explor. during 1881*, No. 14, 1882, p. xxvii.

‡‡ *Rep. Geol. Explor. during 1883-84*, No. 16, 1884, pp. 48, 63-64.

§§ *Trans. N.Z. Inst.*, vol. xix, 1887, pp. 415-450; with sections.

||| *Loc. cit.*, p. 429.

¶¶ *Linn. Soc. Journ.*, Zoology, vol. xxiv, 1891, p. 179.

*** *Trans. N.Z. Inst.*, vol. xxxvii, 1905, pp. 490-551; with map and sections.

††† James Park: *The Geology of New Zealand*, p. 113. Christchurch, 1910.

†††† In James Park, *op. cit.*, pp. 122-123.

In 1912 P. Marshall and George H. Uttley gathered a rich harvest of fossil molluscs from the Awamoan in Target Gully, Oamaru; and at the same time made smaller collections from other horizons of the Oamaruan between Kakanui and the Waitaki.* They agree with the author in placing the Awamoan in the Miocene period.†

Further collections were made by Marshall and Uttley in 1913‡ and 1914,§ and these were identified by Suter, as were their collections of 1912. Their 1913 collection from the Awamoan of Target Gully contained 126 species of Mollusca, of which 36·3 per cent. are Recent. Their 1914 collection from the same place contained 155 species, of which 33 per cent. are living in the New Zealand seas.

Uttley, in his paper|| on "The Geology of Kakanui" (1915), concludes that there is no palaeontological ground for the recognition of a Cretaceous-Tertiary system in the Oamaru district, as previously urged by McKay, and reaffirms this belief in a paper on "The Brachiopod Localities of the Oamaru District."¶

The collections made by the author during the progress of the present survey show that the lowermost marine horizon of the Oamaruan—the Bortonian beds of the Waiarekan stage—contains 23 per cent. of living forms. There is a progressive increase of living species in the intermediate stages till the Awamoan is reached. Of 212 species of Mollusca identified by Suter from the Awamoan Target Gully shell-bed no less than 71, or 33·5 per cent., are Recent. The palaeontological evidence confirms the author's view expressed in 1905 that the whole of the Oamaruan System must be referred to the Miocene period. The Bortonian contains many forms not known elsewhere in New Zealand, and perhaps this sub-stage and the Ngaparan ought to be referred to the Oligocene.

TABULAR STATEMENT OF OAMARUAN STRATA.

Stage-name.	Description of Strata.
Awamoan	Soft marine sandstone, sandy clays, and blue clays with hard flaggy concretionary masses and hard calcareous bands; shelly sands.
Upper Hutchinsonian or Waitakian (sub-stage)	Glaucinitic sandstone with hard calcareous bands.
Lower Hutchinsonian (sub-stage) {	(a) Glaucinitic greensands. (b) Conglomerate (basaltic).
Ototaran	(a) Deborah limestone, in places intercalated with tuffs. (b) Upper Oamaru stone } Around Oamaru these (c) Kakanui tuffs and breccias (fossiliferous), ... } * are replaced by tuffs, or marly clays } tachylitic breccias, and (d) Lower Oamaru stone } basaltic lava-flows.
	(Normal Marine Succession.) (Pyroclastic Succession.)
	(a) Thin-bedded marly clays. (a) Tuffs and basalts; in places (b) Soft brown sandstones. pillow-lavas.
Waiarekan	(c) Hard calcareous glauconitic sandstone bed = Bortonian. (b) Calcareous diatomaceous earth. (c) Tuffs and basalts. (d) Siliceous diatomaceous earth. (e) Tuffs and basalts.
Ngaparan	(a) Limonitic quartzose conglomerates. (b) Loose incoherent grey quartzose sands and fine quartzose drifts, with seam of lignite. (c) Quartzose and sandstone conglomerates.

* *Trans. N.Z. Inst.*, vol. xlv, 1913, pp. 297–307.

† *Loc. cit.*, p. 299.

‡ *Trans. N.Z. Inst.*, vol. xlv, 1914, pp. 279–281.

§ *Trans. N.Z. Inst.*, vol. xlvii, 1915, pp. 377–387.

|| *Trans. N.Z. Inst.*, vol. xlviii, 1916, pp. 19–27.

¶ With the consent of Mr. Uttley, Dr. Thomson has submitted a copy of the manuscript of this paper to the author, containing complete lists of the fossil brachiopods identified by Dr. Thomson and lists of the molluscan collections. Copies of the geological sections were not forwarded. This paper contains an accurate and painstaking description of most of the important Tertiary rock-exposures in the Oamaru district.

THICKNESS OF STRATA

(1.) Awamoan	..	..	..	..	20 ft. to 80 ft.
(2.) Hutchinsonian—					
Upper or Waitakian	..	..	..	..	6 ft. to 40 ft.
Lower (greensands)..	..	..	..	..	4 ft. to 6 ft.
(3.) Ototaran—					
Kakanui (or Deborah) limestone	..	..	..	..	2 ft. to 22 ft.
Kakanui tuffs	..	..	..	..	0 ft. to 150 ft.
Oamaru stone	..	..	..	..	20 ft. to 110 ft.
(4.) Waiarekan—					
Normal marine	..	..	..	..	120 ft.
Tuffs	..	..	..	..	300 ft.
(5.) Ngaparan	..	..	..	..	60 ft. to 320 ft.

CHAPTER IV.

NGAPARAN STAGE.

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- (a) Limonitic quartzose conglomerate.
- (b) Loose incoherent grey quartzose sands and fine quartz drifts, with seam of lignite.
- (c) Quartzose and sandstone conglomerates.

CHARACTER OF ROCKS AND DISTRIBUTION.

THESE rocks are strongly developed between Peebles and Ngapara. At Big Hill they are about 320 ft. thick, but westward of this they appear to become thinner as they approach the ancient strand on which they were laid down.

The basal conglomerates are well exposed in a slip on the face of the high-level terrace immediately opposite Aitchison's Railway-station in the Waitaki Valley, some two miles from Peebles. At this place the mica-schist is overlain by a coarse grey sandstone conglomerate, of which a thickness of 40 ft. is exposed in the slip near the Oamaru Borough water-race. The material composing this conglomerate is mainly decomposed greywacke. Small well-rounded pebbles of quartz, flaky pieces of hard black claystone with rounded edges, and flat pieces of siliceous schist or fissile quartzite, usually decomposed, are also fairly abundant. The larger constituents are set in a matrix of sand and grit. Irregular beds or lenses of sandy material are also present, as well as thin hard limonitic bands.

Scattered throughout the conglomerate there are a few limonitic nodules. The upper 20 ft. of the deposit is coloured brown with limonite. The lower portion is grey or greyish-yellow. No organic remains were found except a few indistinct broken plant-remains in the sandy layers.

An outcrop of mica-schist occurs about 40 yards to the west of the conglomerate outcrop, but the actual contact is obscured by surface soils and Pleistocene high-level gravels. The conglomerate dips south-west at an angle of 8°. On the south-west side of Big Hill the rocks underlying the seam of brown coal or lignite consist of incoherent quartzose sands and grits. These rest on a small patch of the Palæozoic rocks; but they cannot be considered the lowermost member of the coal-measures, as the schist outcrop appears to be a small peak or isolated ridge surrounded and surmounted by Middle Cainozoic quartzose drift.

The summit of Big Hill and the tops of the neighbouring hills are surmounted by a protecting cap of hard coarse limonitic conglomerate dipping gently towards the east. In the hills lying close to Peebles the softer incoherent drifts underlying the hard limonitic conglomerate band have been worn away, with the result that large masses of the conglomerate some acres in extent, being left unsupported, have toppled over bodily, and look like rocks that have been sharply tilted by some earth-movement.

CONDITIONS OF DEPOSITION.

The Ngaparan coal-measures consist of detritus derived from the subaerial denudation of the neighbouring land by streams that discharged their load along the floor

of the sea on a slowly sinking strand. The lowermost deposits filled up the hollows and irregularities of the sea-floor, and covered the submerged ridges and reefs that existed off the shores of the ancient sea. As the sinking of the land progressed the streams pushed their material farther and farther seaward, till at length a wide stretch of land was reclaimed from the sea. The downward movement of the land was now arrested for a time. Vegetation crept down from the higher ground and established itself on the newly reclaimed maritime flats. In these marshy lands bordered by the warm Miocene seas the vegetation grew luxuriantly. The length of this period of quiet growth is unknown; that it was considerable is certain, as the thickness of decaying vegetable matter that accumulated was sufficient to form a seam of lignite 20 ft. thick in places. When favoured with abundant moisture and warmth, peat bogs are now known, as the result of research in Europe, to accumulate at a relatively rapid rate—that is, several feet of thickness may gather in a century. Obviously, the lignite horizon represents but a mere fraction of the Middle Cainozoic.

The swampy jungle-covered lands bordering the coast-line were intersected by numerous creeks and deep-water channels, which prevented the accumulation of a continuous sheet of coal-forming vegetation. Along the banks of these ancient creeks the lignite thins rapidly, and finally disappears.

In the lignite there are sometimes found isolated well-rounded pebbles of quartz ranging in size from $\frac{1}{2}$ in. to 2 in. in diameter. On rare occasions a small number of pebbles may occur close together. Some of these pebbles may have been dropped by birds, but probably the majority of them were brought up from the subsoil by the roots of overturned trees.

FLORA.

The coarse character of the sediments did not favour the preservation of recognizable plant-remains in this area. The flora of the Oamaruan lignitic series will have to be described from some other district. In his *Outline of New Zealand Geology*, 1886, p. 60, Sir James Hector figures a palm-nut from the Ngaparan beds as exposed at the end of the Livingstone Tunnel, on the Windsor Oamaru railway-line. At this place the shales contain numerous fossil fruits, none of which have been described.*

From what is known of the Oamaruan lignitic coal-measures elsewhere in New Zealand, it is almost certain that the Miocene lands of this region were clothed with a forest vegetation which included representatives of the oak, elm, beech, laurel, myrtle, cinnamon, and *Araucaria*. With these grew numerous palms and ferns. In the shales and lignites fossil fruits of proteaceous and coniferous trees are abundant.

* James Park : *Rep. Geol. Explor. during 1886-87*, No. 18, 1887, p. 139.

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NORMAL MARINE SUCCESSION.

- (a) Thin-bedded marly clays.
- (b) Sandstones with fossiliferous flaggy concretions and hard calcareous bands = Bortonian.

PYROCLASTIC SUCCESSION.

- (a) Tufts and basalts; in places pillow-lavas.
- (b) Calcareous diatomaceous earth.
- (c) Tufts and basalts.
- (d) Siliceous diatomaceous earth.
- (e) Tufts and basalts.

CHARACTER AND DISTRIBUTION OF ROCKS.

FROM Oamaru to the south of Kakanui, and from Oamaru to the cross-roads near the head of Horse Creek, which rises at the foot of Big Hill, the Ngaparan quartzose coal-measures are followed by the pyroclastic series of deposits; but on the north side of the Kakanui, about opposite and for a few miles below the mouth of the Kauroo River, and at Papakaio, Windmill Creek (opposite Aitchison's Railway-station), and between Black's and Borton's the Ngaparan is followed conformably by ordinary marine sediments.

NORMAL MARINE WAIAREKAN.

In the Kakanui Valley the Waiarekan strata consist of thin-bedded marly clays that are underlain conformably by soft sandstones. These rocks are well exposed in the steep cliffs fringing the north bank of the Kakanui River from a point about five miles from the Maheno to near the mouth of the Kauroo River. Along the north bank of the Kakanui River the thin-bedded marly clays are seen to emerge from below the Waiarekan tufts, which here reach their westward limits. In their upper portion the marly clays are intercalated with thin beds of black palagonite tuff.

Half a mile farther up the valley the marly clays are underlain by the soft sandstones which form a long line of steep cliffs fronting the Kakanui River, ranging

from 30 ft. to 100 ft. high. These sandstones are glauconitic, slightly micaceous, and yellowish-brown in colour. In places they contain large calcareous concretions that are usually fossiliferous.

A few chains south of the mouth of Lady Jane Creek, which flows past Trigonometrical Station F (210 ft.), close to the edge of the Kakanui River, the sandstones are intruded by a dyke-like sill of dolerite which occupies the higher portion of the cliffs, going down the valley for a distance of about 550 yards. When viewed in mass this rock has a pale greenish-grey colour and granular texture. On weathered surfaces it assumes a spheroidal structure. It is usually much decomposed, and the surface is pitted with cavities due to the removal of the decomposition-products of the augite. In thin section the rock is seen to be a holocrystalline aggregate of plagioclase feldspar and pale-green augite; structure, ophitic. The feldspar is usually clear; it is probably anorthite. The augite occurs in large crystals that are in many cases penetrated by strong laths of feldspar; in the samples of rock broken from the outcrop it is usually decomposed into serpentinous products; but even where highly decomposed the interpenetrating feldspars are fresh and clear. Spines of epidote, iron-ore (mostly the peroxide), grains of calcite, and a little quartz are present as decomposition-products of the augite.

At Enfield and many places on both sides of the Waiareka Stream there are prominent outcrops of dyke-like masses or sills of dolerite that penetrate the Waiarekan sandstones, and reach upwards into the Waiarekan tuffs that north and east of Enfield are intercalated between the Waiarekan sandstones and the Oamaru stone.

The dolerite near Enfield Railway-station is a dark-grey or almost black rock with a fine but easily distinguishable crystalline structure. It penetrates the Waiarekan sandstone, as shown in Fig. 2.



FIG. 2.—SECTION FROM ENFIELD TO THE SOUTH-EAST.

(Distance, one mile.)

a. Micaceous sandstone, pebbly and gritty.
b. Waiareka tuffs.
c. Oamaru stone.

d. Dolerite dyke.
e. Slip and talus.

When examined in thin slice the Enfield dolerite is seen to consist of a holocrystalline aggregate of plagioclase and augite, intergrown so as to develop an ophitic structure. The specific gravity of the rock is 2.94.

At the old coal-mine near Borton's, usually called Black Point Coal-mine, the lignitic beds are followed conformably by a soft brown sandstone, which is interbedded with a band of hard calcareous glauconitic sandstone varying from 6 in. to 2 ft. in thickness. This band is usually coarse in texture, and in places gritty and pebbly. It lies 30 ft. above the seam of lignite, and its importance depends on the circumstance that it is fossiliferous.

The fossiliferous sandstone is overlain conformably by 130 ft. of brown sandy beds that are slightly glauconitic. Overlying these come 15 ft. of greyish sandy beds

that in their upper 5 ft. pass into glauconitic greensands. The latter are followed by the Waitaki stone, a yellowish-brown calcareous sandstone containing thin irregular layers that are somewhat more calcareous, and consequently harder, than the general body of the sandstone.

BORTONIAN FAUNA OF LOWER WAIAREKAN.

Collections of fossils from the sandstone-beds overlying the lignite at Black Point Coal-mine were made by McKay in 1876,* and by the author in 1904,† and again in 1915 during the progress of the present survey. The Mollusca in the author's 1904 collection were named by Captain Hutton. The McKay collection of 1876 and the author's collection of 1915 have recently been examined by Mr. Suter. Many changes have been made in the nomenclature since 1904; and as some of the identifications made at that time by Hutton are doubtful, no account is taken of the 1904 collection.

The species of Mollusca identified by Suter in McKay's 1876 and the author's 1915 collections are given below—

<i>Clio (Styliola) rangiana</i> (Tate).	<i>Cylichnella enysi</i> (Hutt.).
<i>Heliacus imperfectus</i> Sut.	<i>Cylichnella soror</i> Sut.
÷ <i>Turritella carlottæ</i> Watson.	<i>Cucullara alta</i> Sow.
<i>Turritella ambulacrum</i> Sow.	<i>Cucullara australis</i> (Hutt.).
<i>Polinices</i> sp. (young shells only).	<i>Leda semiteres</i> Hutt.
<i>Struthiolaria tuberculata concinna</i> Sut.	÷ <i>Poroleda lanceolata</i> (Hutt.).
<i>Galeodes</i> n. sp.	<i>Melina zealandica</i> Sut.
<i>Latirus elatior</i> Sut.	<i>Limopsis catenata</i> Sut.
÷ <i>Siphonalia mandarina</i> (Duclos).	<i>Pecten hochstetteri</i> Zitt.
÷ <i>Siphonalia nodosa</i> (Märtl.).	<i>Lithophaga nelsoniana</i> Sut.
<i>Parvisipho</i> n. sp. (Genus new to fauna).	÷ <i>Spisula ordinaria</i> (Smith).
<i>Rapana neozelanica</i> Sut.	<i>Crassatellites amplus</i> (Zitt.).
<i>Lapparia hebes</i> (Hutt.).	÷ <i>Ostrea corrugata</i> Hutt. (?).
<i>Surcula</i> n. sp.	<i>Anomia huttoni</i> Sut.
<i>Surcula serotina</i> Sut.	÷ <i>Venericardia difficilis</i> (Desh.).
<i>Sinum (Eunaticina) elegans</i> (?) Sut. (<i>Am-</i>	÷ <i>Dosinia greyi</i> Zitt.
<i>pullina</i> of hand-list).	<i>Chione chiloensis truncata</i> Sut.
<i>Euthriofusus spinosus</i> Sut.	<i>Chione meridionalis</i> (Sow.).
<i>Streptochetus</i> n. sp. (Genus new to fauna).	<i>Cardium waitakiense</i> Sut.
<i>Fulgoraria arabica turrita</i> (?) Sut.	<i>Corbula caniculata</i> Hutt.
<i>Athleta necopinata</i> Sut.	<i>Panope worthingtoni</i> Hutt.
<i>Lyria</i> n. sp. (Genus new to fauna).	<i>Teredo heaphyi</i> Zitt.

÷ Throughout this bulletin the mark (÷) prefixed to the name of a fossil indicates that the species named is living.

The Bortonian is the lowest marine fauna of the Oamaruan in North Otago, if not in New Zealand. It is specially distinguished by the large proportion of gasteropods, many of which are interesting forms. *Parvisipho* n. sp. (McKay, 1876 collection), *Streptochetus* n. sp., and *Lyria* n. sp. (Park collection, 1915) are genera new to the New Zealand fauna.

Of the forty-three species enumerated above, eight (or 18·6 per cent.) are Recent.

In the same horizon there occur the remains of a large crab, *Schizaster rotundatus* Zittel (?), *Flabellum radians* Tenison-Woods, *Balanophyllia hectori* Tenison-Woods, and *Balanus* plates.

* A. McKay : *Rep. Geol. Explor. during 1876-77*, No. 10, 1877, p. 52.

† James Park : *Trans. N.Z. Inst.*, vol. xxxvii, 1905, pp. 520-521.

Near Windmill Creek, immediately opposite Aitehison's Railway-station, and about a mile from Peebles, there occur on the south bank of the Oamaru Borough water-race thin flaggy masses of hard blue mudstone and hard calcareous brown sandstone full of fossil molluscs. These fossiliferous slabs occur in brown sandstones about 80 ft. above the lignitic quartzose beds of the Ngaparan stage, and may represent a somewhat higher horizon than the Bortonian. The molluscs collected here were,—

<i>Turritella concava</i> Hutt.	<i>Dosinia magnu</i> (?) Hutt. jun.
÷ <i>Nucula strangei</i> A. Ad.	<i>Chione chiloensis truncata</i> Sut.
<i>Cucullæa alta</i> (?) Sow.	<i>Chione meridionalis</i> (Sow.).
<i>Melina zealandica</i> (?) Sut.	<i>Cardium spatiosum</i> (?) Hutt.
<i>Crassatellites amplius</i> (?) Zitt.	÷ <i>Psammobia lineolata</i> Gray.
÷ <i>Zenatia acinaces</i> (Q. & G.).	÷ <i>Panope zelandica</i> Gray.
÷ <i>Dosinia greyi</i> Zitt.	

On the banks of the Oamaru Borough water-race, at a point about half a mile below the Papakaio Church, there occur numerous flaggy and nodular masses of hard calcareous mudstone full of fossil shells. These masses could not be traced to their source on account of the overlying sheet of high-level gravels. The underlying rocks for a considerable area around the bend of the water-race, where the fossiliferous masses occur, are the quartzose sandstones, grits, and conglomerates of the lignitic coal-measures; and, with the exception of these and the flaggy masses themselves, there are no other members of the Oamaruan present in this neighbourhood. The masses trail down the slope below the water-race from the edge of the terrace at one place. Their mode of occurrence would tend to show that a patch of the Lower Waiarekan occurs here below the terrace-gravels. The water-race is excavated in sandy clays, and it may be from these that the fossiliferous blocks are derived.

The molluscs identified in a collection made here are,—

<i>Turritella cavershamensis</i> Harris.	<i>Lima colorata</i> Hutt.
<i>Turritella semiconcava</i> Sut.	<i>Crassatellites</i> sp.
÷ <i>Calyptræa alta</i> (Hutt.).	÷ <i>Zenatia acinaces</i> (Q. & G.).
<i>Crepidula gregaria</i> (?) Sow.	<i>Cytherea sulcata</i> (Hutt.).
<i>Polinices gibbosus</i> (Hutt.).	÷ <i>Cytherea subsulcata</i> (Sut.).
<i>Epitonium</i> sp. (?).	<i>Chione meridionalis</i> (Sow.).
<i>Siphonalia subnodosa</i> (?) (Hutt.).	<i>Cardium huttoni</i> (?) von Iher.
<i>Surcula fusiformis</i> (Hutt.).	÷ <i>Psammobia lineolata</i> (?) Gray.
<i>Cucullæa alta</i> Sow.	<i>Corbula canaliculata</i> Hutt.
÷ <i>Limopsis aurita</i> (Brocchi).	<i>Panope worthingtoni</i> Hutt.
<i>Pecten huttoni</i> (Park).	<i>Teredo heaphyi</i> Zitt.

Many of the determinations were based on fragments only. Of the twenty-two species given above, five (equal to 23 per cent.) are living.

The Waiarekan sandstones, which form a line of steep cliffs on the north bank of the Kakanui River from opposite the mouth of the Kauroo River to Black Head, a mile and a half farther up the valley, contain hard concretionary glauconitic masses, from which a few shells in a fragmentary condition were obtained at the mouth of Lady Jane Creek, a mile above the Kauroo River. Among these Suter identified *Surcula fusiformis* (?) Hutton, and *Pholadomya neozelanica* (?) Hutton.

UPPER MARINE WAIAREKAN.

The soft glauconitic sandstones opposite the mouth of the Kauroo River are overlain conformably by thin-bedded marly clays that in their higher portion are intercalated

with thin layers of black palagonite tuff. Lying conformably on the marly clays and tuffs comes the Oamaru stone. Seaward, towards Maheno, the marly clays are replaced by tuffs.

Since they lie immediately below the Oamaru stone, the marly clays may be taken as the representative of the Upper Marine Waiarekan in the Kakanui Valley. The only fossils found in these clays were some Foraminifera, among which the genera *Cristellaria*, *Amphistegina*, *Textularia*, and *Dentalina* were recognized.

Lying between the Lower Waiarekan (Bortonian), at the old coal-mine near Borton's, and the greensands (Lower Hutchinsonian) there are some 130 ft. of slightly glauconitic sandy beds, the lower portion of which must represent the Upper Waiarekan, and the upper the Oamaru stone. To the south-eastward these sandy beds are replaced by tuffs and the Oamaru stone. At Borton's they contain no fossils; but the Upper Waiarekan tuffs are fossiliferous in many places. Hence for the contemporary fauna of the Upper Waiarekan we must depend on the pyroclastic succession.

WAIAREKAN PYROCLASTIC BEDS.

Less than a mile south-south-east of Big Hill, near Peebles, the Waiarekan is completely replaced by tuffs and basaltic lavas that spread out and become thicker towards the coast. At the Teaneraki escarpment the tuffs are nearly 200 ft. thick; at the Cave Valley escarpment, near Enfield, over 300 ft. thick; and at Cape Wanbrow, over 600 ft. thick—though it is possible that a portion of the latter may belong to the Ototaran.

The lower portion of the tuffs is barren of organic remains, but in their upper portion along the western rim of the volcanic zone there are two horizons of diatomaceous earth that probably mark periods of partial or complete cessation of volcanic activity. In the Cape Wanbrow section and at Deborah the tuffs immediately below the Oamaru stone are richly fossiliferous, which may be taken as evidence that the waning phases of the volcanic activity were feeble. The two limestone bands (h^1 and h^2 , Plate II) interbedded with the tuffs in the Cape Wanbrow section doubtless represent two short periods of repose. These bands are composed mainly of Polyzoa. They are brecciated with angular blocks of vesicular basalt, which would indicate that the periods of repose were broken by sharp explosive outbursts which scattered blocks of basalt over the neighbouring sea-floor.

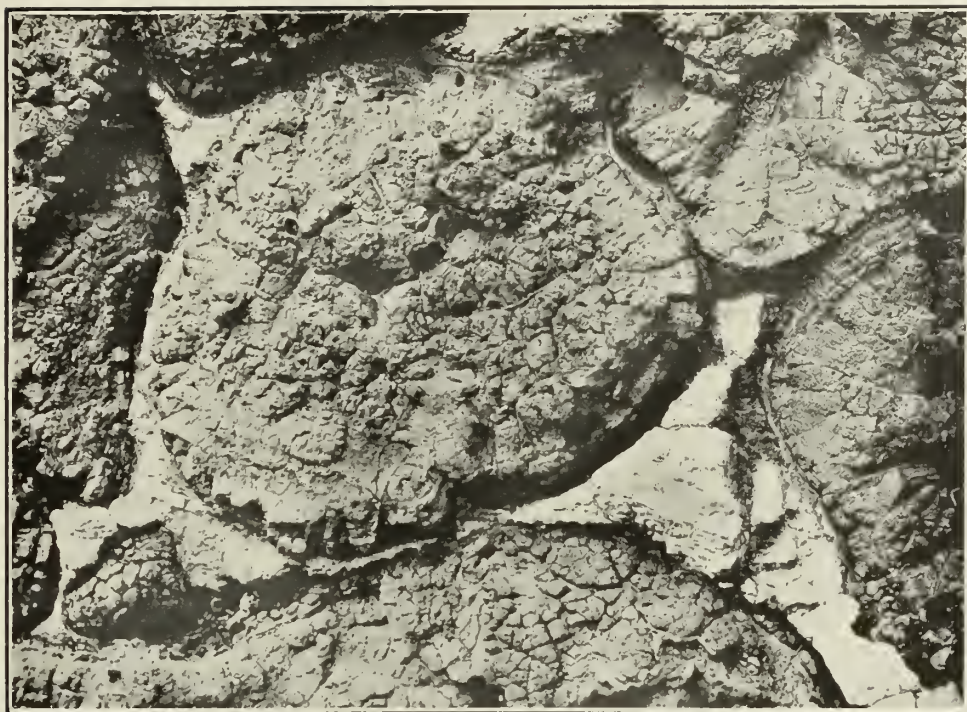
Fauna.—The fauna of the Upper Waiarekan comprises numerous molluscs, brachiopods, echinoderms, corals, Foraminifera, diatoms, and radiolarians. Brachiopods, which become a prominent feature of the Ototaran and Hutchinsonian, make their first appearance in the Upper Waiarekan.

Section from Boatman's Harbour to Cape Wanbrow.

The unbroken line of high perpendicular sea-cliffs between Boatman's Harbour and Cape Wanbrow runs almost at right angles to the strike of the rocks, and presents the most complete section of the Waiarekan succession to be found anywhere in the Oamaru district (see Plate II).

From the breakwater to Boatman's Harbour, a distance of 270 yards, the cliffs are composed of tachylitic breccia with a hard limestone matrix. At Boatman's Harbour the tachylitic breccia is underlain by a series of well-bedded fossiliferous clays, tuffs, and limestone. Below these beds there lies a thick flow of basaltic pillow-lava (f , Plate II). Underlying the pillow-lava for a distance of 340 yards there is a great thickness of well-bedded tuffs (beds g , Plate II). These tuffs vary in colour from pale-grey and bluish-grey muds to dark yellowish-brown or dark greenish-brown tuffs, of texture varying from fine grits to coarse breccias. The coarse tuffs

PLATE IV.



A. C. Gifford, photo.]

A. PILLOW-LAVA, SURROUNDED BY FOSSILIFEROUS LIMESTONE AND CALCITE, BOATMAN'S HARBOUR.



James Park, photo.]

B. PILLOW-LAVA, BOATMAN'S HARBOUR, NEAR OAMARU.

often contain angular blocks of vesicular basalt that are in some places scattered irregularly throughout the mass, in others arranged in more or less well-defined lines.

These bedded tuffs contain two thin limestone-beds, (h^1 and h^2). Bed h^1 lies 17 ft. below the pillow-lava, from which it is separated by beds g , consisting of thin-bedded dark bluish-grey drab-brown tuffs that exhibit well-preserved ripple-marks. In these tuffs there was found a single example of a large *Terebratulina* that closely resembles *Liothyrella boehmi* Thomson, which is abundant in the tuffs immediately underlying the Kakanui limestone.

Limestone-bed h^2 lies from 100 ft. to 150 ft. below bed h^1 . The tuffs between h^1 and h^2 show conspicuous evidence of current-bedding. The angle of dip of bed h^1 is 18° , and of bed h^2 34° . The result of this difference in the angle of dip is that as they rise upward in the cliff-face they rapidly approach one another. Although only a few inches thick—12 in. at the most—these limestone-beds are brecciated with angular blocks of vesicular basalt.

From the lower limestone band (bed h^2) Uttley* collected,—

<i>Emarginula wannonensis</i> Harris.	<i>Liothyrella oamarutica</i> (Boehm).
<i>Siphonalia</i> sp.	<i>Liothyrella boehmi</i> Thomson.
<i>Dentalium solidum</i> Hutt.	<i>Terebratulina suessi</i> (Hutt.).†
<i>Pecten hutchinsoni</i> Hutt.	<i>Ætheia gaulteri</i> (Morris).
÷ <i>Siphonium planatum</i> Sut.	<i>Hemithyris</i> sp., cf. <i>squamosa</i> (Hutt.).

Both bands of limestone are composed mainly of Polyzoa.

A marked stratigraphical discordance exists between the lower limestone band (h^2) and the underlying tuffs. The limestone-bed and overlying tuffs strike 101° - 102° (magnetic), and dip north at an angle of 31° , while the tuffs below the limestone strike 11° - 12° (magnetic), or at right angles to the limestone. As one proceeds still farther southward towards Cape Wanbrow the bedded tuffs (g) are found to rest on coarse dirty bluish-green tuffs that exhibit no bedding. These occupy the sea-cliffs for nearly 300 yards, when they are suddenly cut off by a fault, south of which the cliffs are composed of well-bedded tuffs for a distance of 170 yards, when they are in their turn cut off by a basaltic dyke which is also a fault-plane. From the basaltic dyke southward to Cape Wanbrow the cliffs are composed of coarse dirty bluish-green tuffs that show no bedding-planes. Near the centre of the anticline one of the tuff bands is confusedly contorted, as if it alone had been subjected to lateral compression.

The basaltic dyke strikes nearly north and south, and runs across the Wanbrow promontory, appearing on both sea-faces. It varies from 3 in. to 12 in. wide, and stands almost vertically. Considerable fault-displacement has taken place on its south wall, with the result that the tuffs on that side have been crushed and shattered for a width of 15 ft., as seen on the south side of Cape Wanbrow. This fault was first described by the author in 1904.‡ At that time the dyke lying on the north wall was not noticed, owing to intense weathering.

On the north side of Cape Wanbrow this dyke is seen to be only one of many thin vein-like dykes of basalt that in this neighbourhood intersect the tuffs in all directions (Plate III). They are well exposed on the broad rock-platform of marine erosion lying below high-water mark. This platform extends from Cape Wanbrow to Oamaru Breakwater.

To the southward of Cape Wanbrow the coast-line runs almost due west for 260 yards, then south-west for 500 yards, and beyond that westward for half a mile.

* G. H. Uttley: "The Brachiopod Localities of the Oamaru District" (MS.), 1915.

† Recorded by Uttley as *T. oamarutica* Boehm. This species, however, is regarded by Thomson as a synonym of *T. suessi* (Hutton).

‡ James Park: *Trans. N.Z. Inst.*, vol. xxxvii, 1905, p. 515. Fault is shown in Fig. 7.

A generalized section showing the arrangement of the tuffs and overlying beds between Cape Wanbrow and the Rifle Butts is shown in Fig. 3. South of the basaltic dyke (*k*, Fig. 3) the well-bedded tuffs (*g* of Fig. 3 and of Plate II) dip at first eastward at an angle of 30° ; but to the southward they appear in the sea-cliffs as horizontal strata, due to the change in the trend of the coast-line.

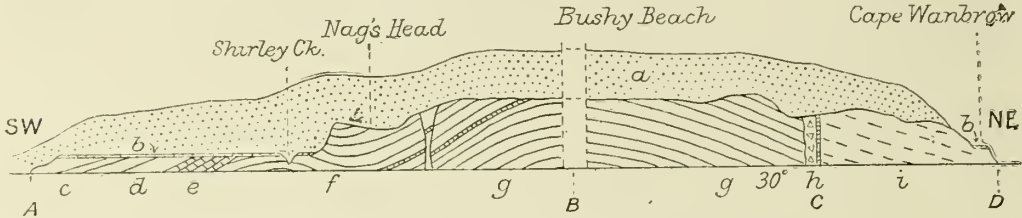


FIG. 3.—SECTION FROM CAPE WANBROW TO RIFLE BUTTS.

- | | |
|--------------------------------|--|
| <i>a.</i> Pleistocene silts. | <i>f.</i> Yellowish-brown coralline tuffs. |
| <i>b.</i> Raised beach, 12 ft. | <i>g.</i> Well-bedded tuffs. |
| <i>c.</i> Awamoan beds. | <i>i.</i> Tuffs with no bedding. |
| <i>d.</i> Hutchinsonian beds. | <i>k.</i> Basaltic dyke and fault. |
| <i>e.</i> Ototaran beds. | |

The relationship of the Waiarekau tuffs to the Ototaran is well seen in the sea-cliffs near Shirley Creek, 500 yards north of the Rifle Butts (see Fig. 3 and measured section at Rifle Butts, Plate IV).

Section at Boatman's Harbour.

The relationship of the pillow-lava to the overlying fossiliferous beds at this place is shown in Plate II, and in Fig. 4, which shows the beds on a larger scale.

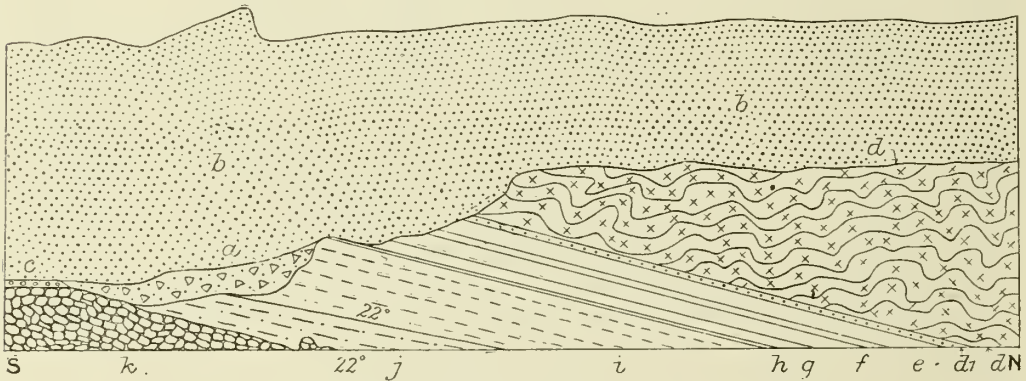


FIG. 4.—SECTION ACROSS BOATMAN'S HARBOUR.

(Scale, horizontal and vertical, 30 ft. = 1 in.)

- | | |
|---|---|
| <i>a.</i> Slope deposit. | <i>h.</i> Blue thin-bedded mudstone; at base interbedded with two thin bands of hard limestone each 2 in. to 4 in. thick, the lower pebbly and tufaceous. |
| <i>b.</i> Pleistocene silts. | <i>i.</i> Dirty-brown calcareous tuffs; 15 ft. to 18 ft. |
| <i>c.</i> Raised beach, 12 ft. | <i>j.</i> Current-bedded tuffs, greyish-green in colour, coarse in lower 5 ft., finer in higher 4 ft.; 9 ft. |
| <i>d.</i> Tachylitic breccia. | <i>k.</i> Basaltic pillow-lava, with fossiliferous limestone between pillows. |
| <i>d</i> ₁ . Basaltic breccia in tuff matrix; 2 ft. to 4 ft. | |
| <i>e.</i> Greenish tuffs passing upward into buff-coloured tuffs of fine texture; 4 ft. | |
| <i>f.</i> Green tuffs with broken shells and corals. | |
| <i>g.</i> Yellowish-brown tufaceous limestone, from 3 ft. to 3 ft. 3 in. | |

The pillow-lava shows a thickness of 85 ft. or 90 ft. It was described as such by the author* in 1905, and this was the first record of the occurrence of this peculiar lava structure in New Zealand. The pillow-lava as seen in the cliff-face consists of spheroidal and pillow-form masses ranging mainly from about 8 in. to 14 ft.

* James Park: *Trans. N.Z. Inst.*, vol. xxxvii, 1905, p. 513.

in diameter. In the platform worn in the pillow-lava, sack-shaped masses varying from 2 ft. to 6 ft. or even 8 ft. long are common. The spaces between the pillows are filled with limestone or hard calcareous fossiliferous sandstone veined with calcite. In some cases the pillows are completely surrounded with sedimentary material and secondary calcite (A, Plate V). The central portion of each pillow is an olivine dolerite consisting of feldspar, olivine, and augite; while the outer skin is a black basic glass from $\frac{1}{4}$ in. to 1 in. thick. In thin slice this vitreous crust is seen to consist of dark-brown glass, with numerous plagioclase laths and scattered grains of olivine. The gradual change from the glassy to the crystalline rock can be easily traced in the pillows exposed in section in the cliff-face.

From the interstitial limestone in the pillow-lava Uttley* collected *Trochus* sp., *Turritella* sp., *Polinices huttoni* von Iher., *Lima bullata* (Born), *Lima lima* (L.), *Ostrea* sp., *Cardium* sp., *Hemithyris* sp. cf. *squamosa* (Hutton), and the coral *Isis* sp. (?). In addition to these the author found numerous Polyzoa, many examples of a small echinoderm resembling *Gagaria*, and Foraminifera.

The current-bedded tuffs immediately overlying the pillow-lava are not fossiliferous; but from the calcareous tuffs (bed *i* of Fig. 4) were collected *Epitonium lyratum* (Zitt.), *Venericardia difficilis* (Desh.), *Ostrea* sp., *Cucullaea alta* Sow., and *Diplodonta zelandica* (Gray). In this bed Uttley (l.c.) found *Lima jeffreysiana* Tate.

From the upper of the two thin limestone-beds at base of bed *h*, Fig. 4, Uttley (l.c.) collected *Epitonium lyratum* (Zitt.), *Pecten hutchinsoni* Hutt., *Pecten delicatulus* Hutt., *Terebratulina suessi* (Hutt.), *Liothyrella boehmi* (?) Thomson, and *Liothyrella oamarutica* (Boehm). Additional forms collected by the author were *Polinices* sp., *Glycymeris* sp., *Cardium huttoni* (?) von Iher., and *Neothyris uttleyi* Thomson (MS.).

From bed *g*, Fig. 4, Uttley (l.c.) collected *Limopsis aurita* (Brocchi), *Pecten delicatulus* Hutt., *Lima jeffreysiana* Tate, *Ostrea* sp., *Venericardia difficilis* (Desh.), *Venericardia zelandica* (Desh.), *Protocardia pulchella* (Gray), *Terebratulina suessi* (Hutt.).

RELATIONSHIP OF CAPE OAMARU TUFFS TO THE OTOTARAN.

Between the Rifle Butts and Boatman's Harbour—a shallow cliff-bound cove 250 yards south of the breakwater—the Miocene strata are arranged in a great anticlinal fold, with a minor synclinal fold on the south limb of the anticline between Shirley Creek and Nag's Head (Fig. 3).

At Shirley Creek the Waiarekan tuffs are overlain unconformably by the Oamaru stone and associated beds (Plate IV). The stratigraphical discordance is well seen in the cliff-face and on the beach platform, on which the divergent lines of outcrop are conspicuously outlined at low water (see B, Plate VI). The unconformity cannot be regarded as other than intra-formational, and an evidence that the rapidly formed and loosely compacted Waiarekan ash-beds were unable to offer much resistance to the prevailing coastal currents, and at the same time were affected by local earth-movements arising from their nearness to a centre of volcanic activity.

On the north side of the anticline the Oamaru building-stone is absent, and, if not wholly, is partly represented by the fossiliferous tuffs and limestones at Boatman's Harbour. The brachiopods from the upper of the two limestone bands at that cove are mostly those of the Kakanui limestone horizon of the Ototaran, as also are the brachiopods from the lower of the two limestone-beds underlying the pillow-lava.

The stratigraphical unconformity between *h*² and the underlying tuffs (Plate II) may possibly represent the break seen at Shirley Creek (Plate IV and Fig. 3). This

* G. H. Uttley: "The Brachiopod Localities of the Oamaru District" (MS.), 1915.

break, as it appears near Boatman's Harbour (Plate II) and at Shirley Creek (Plate IV), cannot be held to possess any great significance, as it is apparently due to contemporaneous erosion.

SHIRLEY CREEK SECTION NORTH OF RIFLE BUTTS.

The Waiarekan tuffs between Nag's Head to a point a little south of Shirley Creek contain two or three thin fossiliferous bands (beds *v*, *t*, and *r*, Plate IV). Beds *t* and *r* may possibly represent the same horizon. The yellowish-brown tuffs marked *s* are largely composed of broken Polyzoa. Molluscs are also present, but are too fragmentary for identification.

From bed *v* were collected *Venericardia difficilis* (Desh.) and *Liothyrella oamarutica* (Boehm). Many more forms occur in this bed, but the matrix—secondary calcite—is so hard, and the rock-exposure so small, that no success was achieved in the extraction of recognizable forms.

Bed *t*, though thin, is softer and sandy, and from it were collected,—

- | | |
|--|--|
| ÷ <i>Astræa heliotropium</i> (?) (Mart.). | ÷ <i>Mytilus caniculatus</i> (?) Mart. |
| <i>Calliostoma acutangulum</i> Sut. | <i>Polinices ovatus</i> (Hutt.). |
| ÷ <i>Dosinia greyi</i> (?) Zitt. | <i>Struthiolaria tuberculata</i> (?) Hutt. |
| <i>Epitonium lyratum</i> (Zitt.). | <i>Teredo heaphyi</i> Zitt. |
| <i>Ficus parvus</i> Sut. | <i>Venericardia purpurata</i> (Desh.). |
| ÷ <i>Glycymeris laticostata</i> (Q. & G.). | Young specimens having a few radial ribs more than the typical form. |

The only brachiopod from this bed was *Terebratulina suessi* (Hutton), which is abundant. Polyzoa are numerous, and a small echinoderm also occurs.

From bed *r*, which lies immediately below the Ototaran beds, were collected,—

- | | |
|---|---|
| <i>Ancilla hebera</i> (Hutt.). | <i>Ostrea wuellerstorfi</i> Zitt. (fragments). |
| ÷ <i>Astræa heliotropium</i> (Mart.). | <i>Panope orbita</i> Hutt. |
| ÷ <i>Calyptræa maculata</i> (Q. & G.). | <i>Pecten hutchinsoni</i> Hutt. (fragments). |
| ÷ <i>Cardita calyculata</i> (L.) (new for the Miocene). | ÷ <i>Psammobia lineolata</i> (?) Gray (fragment). |
| <i>Crassatellites amplus</i> (Zitt.). | <i>Teredo heaphyi</i> Zitt. |
| ÷ <i>Crassatellites obesus</i> (A. Ad.). | ÷ <i>Venericardia purpurata</i> (Desh.). |
| <i>Cytherea sulcata</i> (?) (Hutt.) (fragment). | <i>Venericardia pseutes</i> Sut. |
| ÷ <i>Diplodonta zelandica</i> (Gray). | <i>Calliostoma</i> n. sp. |
| <i>Lima colorata</i> Hutt. | <i>Trochus</i> n. sp. |
| <i>Mactra attenuata</i> Hutt. | <i>Pecten</i> n. sp. (radially microscopically striated). |
| ÷ <i>Mytilus magellanicus</i> Lamk. | |

CONFIRMATORY SECTIONS.

Many sections confirmatory of the inferior position of the Waiareka tuffs to the Oamaru stone are exposed in the great limestone escarpments extending from Teaneraki to Cave Valley, from Cave Valley to Teschemaker's, from Teschemaker's to Maheno, from Totara to One Tree Hill, and from Totara to Deborah. Good sections showing the same relationship may be seen at Brockman's Hill, Tabletop Hill, and Landon Creek.

Section at old Quarry, Awamoa Creek, near Deborah.

In the bottom of the old quarry there is a flow of basalt that, on the east side of the cutting, possesses a pillow structure similar to that seen at Boatman's Harbour. The pillow-lava is overlain by a bed of fossiliferous calcareous tuffs. Over the fossiliferous

tuffs lies a soft yellowish-brown polyzoan sandstone, in places tufaceous. Then follows the Oamaru stone, the typical building-stone.

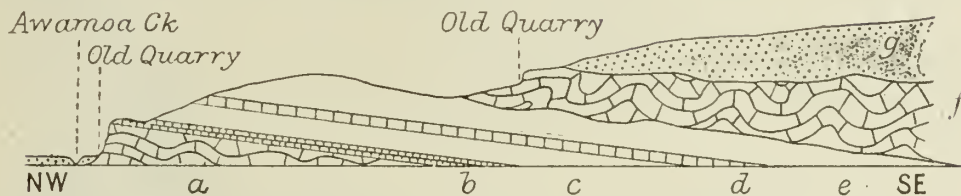


FIG. 5. SECTION THROUGH OLD STONE-QUARRIES, UPPER AWAMOIA CREEK, NEAR DEBORAH.

- | | |
|--|--|
| a. Basalt, in places showing pillow-lava structure. | d. Oamaru building-stone; 10 ft. |
| b. Yellowish-brown calcareous tuffs, fossiliferous; 8 ft. | e. Unknown, 30 ft. (probably calcareous tuffs). |
| c. Soft yellowish-brown polyzoan sandstone, with pale-green tufaceous matter in places; 42 ft. | f. Basalt showing pillow-lava structure at south-east end of quarry. |
| | g. Yellowish-brown Pleistocene silts. |

The calcareous tuffs (b) fill the interstices between the uppermost pillows, as shown in Fig. 6. The pillows generally vary from 1 ft. to 2 ft. in diameter, but the large pillow shown in the middle of Fig. 6 measures 18 ft. by 12 ft.

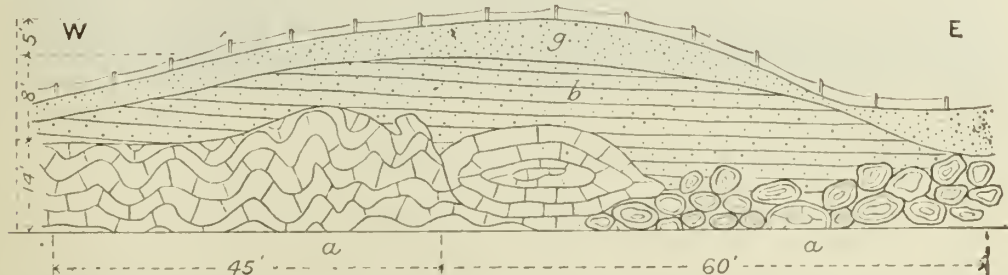


FIG. 6.—SECTION OF OLD QUARRY-FACE, UPPER AWAMOIA CREEK, NEAR DEBORAH, SHOWING PILLOW-LAVA (BELOW OAMARU STONE).

- | | | |
|-----------------|--------------------------------------|-----------------------|
| a. Pillow-lava. | b. Yellowish-brown calcareous tuffs. | g. Pleistocene silts. |
|-----------------|--------------------------------------|-----------------------|

The tuffs overlying the pillow-lava contain many molluscs and a large solid branching coral, *Oculina oamaruensis* Park. Brachiopods seem to be absent.

The molluscs identified from this horizon were,—

Chione meridionalis (?) (Sow.).

÷ *Crassatellites obesus* (A. Ad.).

Cucullæa attenuata (?) Hutt.

÷ *Glycymeris laticostata* (Q. & G.).

÷ *Lima angulata* Sow.

Lima colorata (?) Hutt.

Lima paleata (?) Hutt.

Melina zealandica Sut.

÷ *Mesodesma australe* (Gmel.).

÷ *Modiolus australis* (?) (Gray).

÷ *Ostrea angasi* (?) Sow.

Ostrea wuellerstorfi Zitt.

Panope orbita Hutt.

Panope worthingtoni Hutt.

Pecten aldingensis Tate.

Pecten burnetti Zitt.

Pecten marshalli (?) Sut.

÷ *Placunanomia zelandica* (Gray).

Protocardia sera Hutt.

÷ *Siphonium planatum* Sut.

Teredo heaphyi Zitt.

Turbo, cf. *superbus* Zitt. (casts).

Turritella cavershamensis (?) Harris.

÷ *Venericardia difficilis* (?) (Desh.).

Of the above twenty-four species, nine (or 37·5 per cent.) are Recent. Writing of this collection Mr. Suter says that most of the fossils are in bad condition for identification. A number of specimens, no doubt representing extinct species, could not be identified, and therefore the percentage of Recent forms may safely be taken at a lower figure.

Section at Trig. V, near Teschemaker's old Homestead.

The fine escarpment running from Totara to Teschemaker's old homestead, situated in the lower end of the Waiareka Valley, is surmounted by the Oamaru stone (Plate VII). Below the limestone lie the Waiareka tuffs, which spread westward to the Kakanui River and northward to Enfield. They occupy the core of the Waiareka anticline, which is flanked on both sides by the Oamaru stone, as shown in Fig. 9.

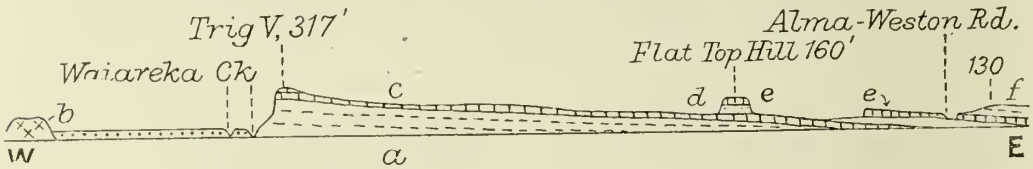


FIG. 7.—SECTION FROM WAIAREKA CREEK EASTWARD TO ALMA-WESTON ROAD.
(Horizontal scale, 30 chains = 1 in. ; vertical scale, 660 ft. = 1 in. Distance, $1\frac{1}{4}$ miles.)

- | | |
|---------------------------|------------------------------------|
| a. Waiareka tuffs. | d. Kakanui (or Deborah) tuffs. |
| b. Basaltic dyke. | e. Kakanui (or Deborah) limestone. |
| c. Oamaru building-stone. | f. Greensands. |

A good section of the Waiareka tuffs is exposed in the steep face descending from Trig. V to the Waiareka Stream. The tuffs at this place are about 275 ft. thick, and apparently unfossiliferous. They consist of well-bedded ash, varying from drab to dark-brown and greenish-brown in colour. At the few places where the junction of the tuffs and Oamaru stone is not obscured by fallen blocks of limestone the tuffs appear to be conformably overlain by the Oamaru stone.

Section in Railway-cutting South of Teschemaker's Railway-station.

A good section of the actual contact of the Waiareka tuffs and Oamaru stone is exposed in the deep railway-cutting beginning 60 yards south of Teschemaker's Railway-station, and descending by a steep gradient towards the Kakanui River at Maheno. The beds are gently curved or almost horizontal. (B, Plate VII and Fig. 8.)

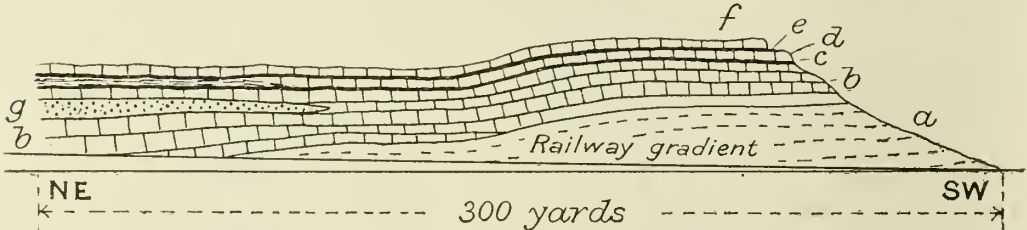


FIG. 8.—SECTION OF RAILWAY-CUTTING IMMEDIATELY SOUTH OF TESCHEMAKER'S RAILWAY-STATION.

- | | |
|---|---|
| a. Waiareka tuffs—thin-bedded brownish-green volcanic ash, mostly fine in texture; thickness of 30 ft. showing at south end of cutting. | c. Fine-grained yellow or pale-brown calcareous tuff or volcanic mud, 10 in. to 12 in. thick. |
| b. Oamaru stone, 18 ft. thick. | d. Oamaru stone, 12 in. to 16 in. thick. |
| | e. Same as c; 8 in. to 14 in. thick. |
| | f. Oamaru stone; thickness of 6 ft. remaining. |

Near the middle of the cutting a wedge-shaped bed of yellow tufaceous clay splits the lower bed of Oamaru stone (b) into two bands. The point of the wedge is directed towards the south-west—that is, towards the Kakanui Valley. In the direction of Teschemaker's the clay band rapidly increases in thickness, and in a distance of 50 yards it has widened out to a thickness of 9 ft. At 90 yards from the point of the wedge this clay band begins to decrease in thickness, and, going northwards from here, is intercalated with two thin layers of Oamaru stone. Near the place where the main bed of Oamaru stone (b) is split by the wedge of clayey tuffs, the middle bed of Oamaru stone (d, Fig. 7) disappears and clay beds (c and e) come together.

PLATE V.



A. C. Gifford, photo.]

A. NAG'S HEAD, NEAR SHIRLEY CREEK. VIEW SHOWS FOSSILIFEROUS TUFFS.



A. C. Gifford, photo.]

B. VIEW NEAR SHIRLEY CREEK, SHOWING CONGLOMERATE AT BASE OF OAMARU LIMESTONE AND ITS JUNCTION WITH WAIAREKAN TUFFS.

Section from Kakanui River to Totara.

In the section the Waiareka tuffs are exposed in the core of the Waiareka anticline.

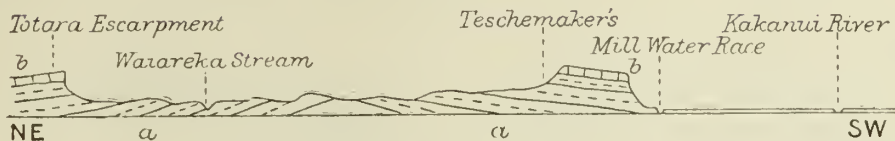


FIG. 9.—SECTION FROM KAKANUI RIVER TO TOTARA.

(Distance, 2½ miles.)

a. Waiareka tuffs.

b. Oamaru stone.

In the railway-cutting 200 yards south of the railway-bridge across the Waiareka Stream the Waiareka tuffs are exposed on the south-west limb of the Waiareka anticline for a distance of 48 yards. Their strike is north-north-west-south-south-east, and the dip west-south-west at an angle of 37° . Here the material consists of volcanic ash varying from fine to gritty in texture, and ranging from yellowish-brown to olive-green and purple in colour. The tuffs are interleaved with thin sheets of grey secondary calcite, or veined with calcite veins that follow cracks and joint-planes.

In the railway-cutting at mile-post 165 the dip varies from 20° at the north end to 7° at the south end. Here the material is fine or gritty, the coarser bands being brecciated with small angular fragments of basalt usually much decomposed. The fragments are mostly 1 in. or less in diameter. Blocks of basalt 6 in. in diameter are scattered throughout the beds of finer material. The colour of the ash varies from rich vandyke brown to dark drabby purplish brown.

The total length of exposure in this cutting is 200 yards. About 50 yards south of the overbridge spanning the cutting the tuffs are interbedded with a strikingly conspicuous bed of leek-green tuff, 12 ft. thick. This bed of green tuff is intercalated with irregular nodular layers of calcareous tuff; and in these layers occur many curious branching *Polyzoa* from $\frac{1}{2}$ in. to 1 in. in diameter. With the *Polyzoa* there occur *Pecten delicatulus* Hutt. and *Venericardia acanthoides* Sut.

The dip of the tuffs in this cutting is variable, the rapid changes being often due to current-bedding. The strike is east-west, and the dip south.

At 66 yards farther south there is a second band of leek-green tuff varying from 6 in. to 10 in. thick.

A quarter of a mile north of Totara Railway-station the tuffs in the railway-cutting are intercalated with a flow of basalt showing a well-developed pillow structure.

Section near Maheno Flour-mill.

About 180 yards below the mill, in the face of the steep escarpment which forms the north wall of the Kakanui Valley east of the railway-line, there is a good exposure of the actual contact of the Waiareka tuffs and Oamaru stone.

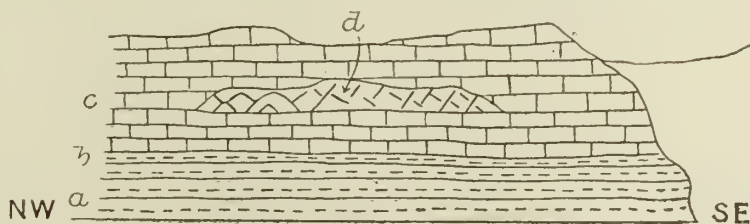


FIG. 10.—SECTION NEAR MAHENO MILL, KAKANUI VALLEY.

a. Waiareka tuffs.
b. Chalky clays

c. Oamaru stone.
d. Basalt sill; greatest thickness, 12 ft.

At this place the Oamaru stone is intruded by a sill of basalt. Between the Waiareka tuffs and the Oamaru stone there is a bed of chalky clay varying from 2 ft. to 4 ft. thick.

In a bed of fine tuff a few feet below the chalky clay some interesting molluscs were found :—

<i>Clio (Styliola) annulata</i> (Tate).	÷ <i>Divaricella cumingi</i> (Ad. & Ang.).
<i>Crepidula densistria</i> Sut.	<i>Cardium</i> n. sp.
÷ <i>Pupa alba</i> (Hutt.).	<i>Cardium</i> n. sp.
<i>Cylichnella enysi</i> (Hutt.).	÷ <i>Protocardia pulchella</i> (Gray).
<i>Dentalium</i> n. sp.	<i>Teredo heaphyi</i> Zitt.
<i>Amusium zitteli</i> (Hutt.).	<i>Cuspidaria</i> n. sp.

Of twelve species enumerated above, four are new, and one, *Clio (Styliola) annulata* Tate, is new to the New Zealand fauna.

In the same bed were found *Schizaster rotundatus* Zitt., and crab-remains, as well as the brachiopods *Etheia gaulteri* (Morris) and *Neothyris tapirina* (Hutt.).

About 300 yards from the mill, in the face of the same escarpment, the tuffs are invaded by a sill of basalt that occupies the lower portion of the cliff for a considerable distance.

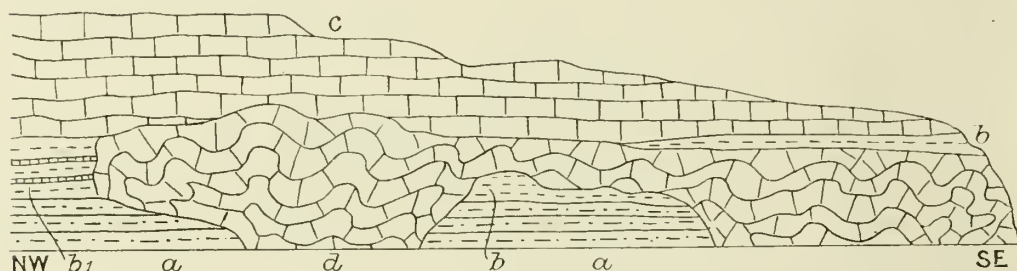


FIG. 11.—DIAGRAMMATIC SECTION OF SCARP-FACE 300 YARDS SOUTH-EAST OF MAHENO MILL, KAKANUI VALLEY.

a. Waiareka tuffs. c. Oamaru stone.
b. Grey chalky clays with limestone bands. d. Basaltic sill.

Still farther down the Kakanui Valley the Waiareka tuffs are found to be strongly developed at Taipo Hill, which is a tuff cone 300 ft. high, in many places seamed with narrow dykes of basalt. On the north bank of the Kakanui River due west of the summit of Taipo Hill one of these dykes, through the denudation of the softer tuffs, now stands up conspicuously as an unsupported wall to a height of nearly 25 ft. This dyke strikes north-east—south-west. It varies from $2\frac{1}{2}$ ft. to 3 ft. thick, and shows a well-developed columnar structure in which the prisms lie at right angles to the plane of the walls.

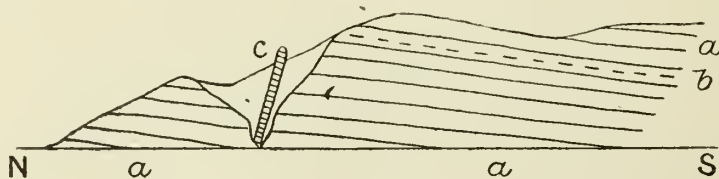


FIG. 12.—SECTION OF NORTH BANK OF KAKANUI RIVER, A QUARTER OF A MILE DUE WEST OF TAIPO HILL. (Distance, 65 yards.)

a. Thin-bedded brown tuffs. b. Palagonite tuff; 6 ft. c. Basaltic dyke; 2.5 ft. to 3 ft.

Section from Big Hill to Landon Creek.

The relationship of the Waiarekan tuffs to the Ngaparan coal-measures lying below them and to the Oamaru stone lying above is well seen in the section from Big Hill to the south-west branch of Landon Creek.

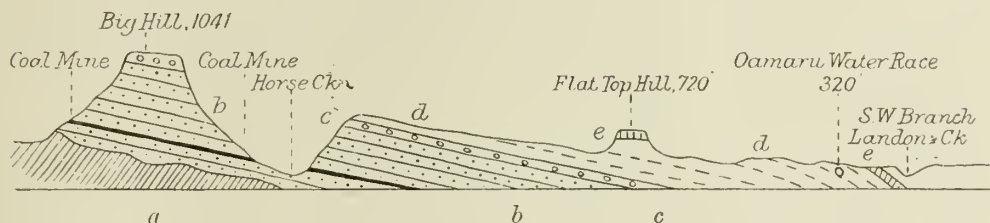


FIG. 13.—SECTION FROM BIG HILL TO LANDON CREEK.

(Distance, $4\frac{1}{2}$ miles.)

- | | |
|---|--|
| a. Palaeozoic phyllite and mica-schist. | c. Band of hard limonitic conglomerate. |
| b. Quartzose sands and conglomerates with seam of brown coal. | d. Waiareka tuffs. |
| | e. Oamaru stone overlain by glauconitic sandstone. |

Section on East Bank of Lower End of Grant's Creek.

Grant's Creek is the north-east branch of Oamaru Creek. It joins Oamaru Creek near Ardgowan Post-office. On the left bank of Grant's Creek, about 400 yards from Ardgowan Road junction and church reserve, there is a good exposure of the Waiarekan tuffs and overlying Oamaru stone. Here in ascending order we have tuffs, basaltic conglomerate, Oamaru stone, basaltic conglomerate, and Oamaru stone. Less than 50 yards higher up the stream, and on the same side, the Oamaru stone is followed by the Hutchinsonian greensands crowded with *Pachymagas parki* (Hutton). The section exposed in the low cliffs about 30 yards above the farm homestead is shown in Fig. 14.

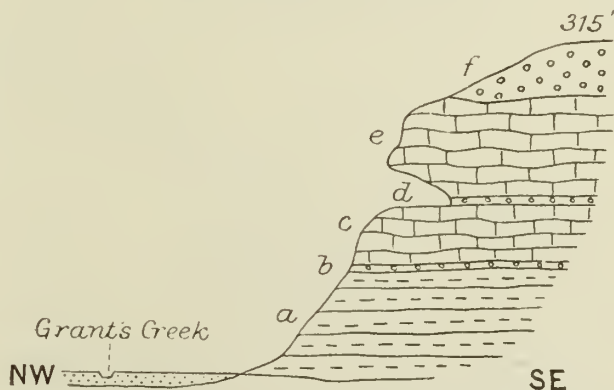


FIG. 14.—SECTION ON EAST BANK OF GRANT'S CREEK, 400 YARDS ABOVE ARDGOWAN ROAD JUNCTION.

- | | |
|---|--|
| Soft friable greenish tuffs, glauconitic, calcareous, and fossiliferous, 8 ft. showing. | c. Yellowish-brown calcareous sandstone, 6 ft. thick. |
| b. Bed of basaltic conglomerate varying from 3 in. to 6 in. thick. | d. Bed of basaltic conglomerate, 2 ft. to 4 ft. thick. |
| | e. Oamaru stone, 10 ft. showing. |
| | f. Surface soil and gravels. |

The tuffs contain numerous Polyzoa, echinoderm remains, and broken shells, all too fragmentary for satisfactory identification.

The conglomerate bands probably owe their origin to the contemporaneous marine erosion of portions of the tuff platform that stood a little above sea-level or were just awash, and hence subject to the wear-and-tear of the tides and coastal sea-currents.

Section on North Side of North-west Branch of Landon Creek.

In the upper basin of this stream there is a great development of the Waiarekan tuffs. The tuffs are followed by the lower and upper bands of Oamaru stone, which, as at Kakanui, are separated by a considerable thickness of dark greenish-brown tachylitic breccia, in which there occur many minerals, including dark-coloured augite, hornblende, garnet, and feldspar. The strike of these rocks is north-east-south-west, and their dip south-east at angles varying from 40° to 45° . Down the stream the dip flattens, and when the upper band of Oamaru stone is reached the angle of dip varies from 15° to 20° .

The lower limestone band is glauconitic, and contains a layer of calcareous tuff. The thickness of the tachylitic breccia and associated beds cannot be ascertained, on account of slope deposits covering the line of junction between it and the enclosing limestones, but the uniform dip and strike leave no doubt as to their relationship to one another.

The upper glauconitic limestone is followed by a bed of hard grey semi-crystalline limestone, varying from 16 in. to 30 in. thick. Overlying this bed is a deposit of glauconitic greensands crowded with molluscs, brachiopods, and Polyzoa. The greensands are about 14 ft. thick. They are overlain by a bed of hard dark yellowish-brown calcareous sandstone, also containing molluscs and brachiopods.

The beds represented in this valley are thus—

Hutchinsonian	{	(g) Hard brown glauconitic sandstone; thickness, 6 ft. exposed; fossiliferous.
		(f) Glauconitic greensands, 14 ft; fossiliferous.
Ototarā ..	{	(e) Hard grey semi-crystalline limestone, 16 in. to 30 in.
		(d) Glauconitic limestone (Upper Oamaru stone), 50 ft. thick; exposed.
		(c) Tachylitic mineral breccia, calcareous.
		(b) Glauconitic limestone (Lower Oamaru stone).
Waiarekan ..	{	(a) Dark greenish-brown tuffs.

The transverse section across the mouth of the gully near the county road is shown in Fig. 15.

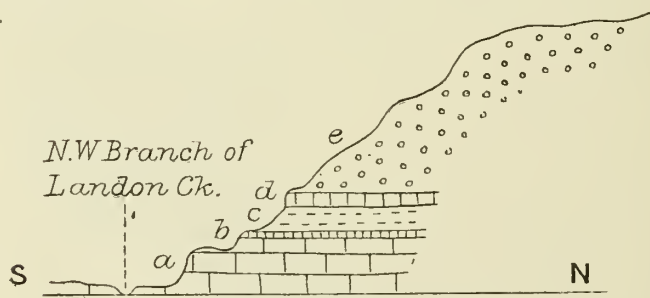


FIG. 15.—TRANSVERSE SECTION AT MOUTH OF WEST BRANCH OF LANDON CREEK.

a. Upper band of Oamaru stone, 24 ft. showing.

b. Bed of hard semi-crystalline limestone.

c. Glauconitic greensands, crowded with *Pachymagas parki* (Hutt.).

d. Hard brown calcareous sandstone, thickness of 6 ft. exposed, with *Pecten huttoni* (Park) (abundant), *Meoma crawfordi* Hutton (= *Pericostmus compressus* McCoy), &c.

e. High-level Pleistocene gravels.

From the upper portion of bed a, Fig. 14, were obtained the molluscs *Epitonium lyratum* (Zitt.), *Pecten delicatulus* Hutt., *P. polymorphoides* Zitt., and *Ostrea* sp. From this bed Uttley records the following brachiopods:—

Liothyrella boehmi Thomson.

Liothyrella landonensis Thomson.

Ætheia gaulteri (Morris).

Terebratulina suessi (Hutt.).

Hemithyris squamosa (?) (Hutt.).

Pachymagas ellipticus Thomson.

Rhizothyris rhizoida (Hutt.).

From the greensands bed c, Fig. 14, the author collected the molluscs—

<i>Epitonium zelebori</i> (Dkr.).	<i>Pecten huttoni</i> (Park).
<i>Pecten beethami</i> Hutt.	<i>Pecten semiplicatus</i> Hutt.
<i>Pecten burnetti</i> Zitt.	<i>Crassatellites obesus</i> (A. Ad.) ?
<i>Pecten hutchinsoni</i> Hutt.	<i>Chione meridionalis</i> (Sow.) ?

The brachiopods obtained from the greensands included—

<i>Liothyrella landonensis</i> Thomson.	<i>Pachymagas parki</i> (Hutt.) (very abundant).
<i>Hemithyris</i> sp. (?)	
<i>Murrawia catinuliformis</i> (Tate).	<i>Rhizothyris rhizoida</i> (Hutt.).

This bed also contains numerous corals, including *Isis dactyla* Ten.-Woods, cup-shaped bryozoans in great abundance, long *Cidaris* spines, *Cidaris* plates, and Foraminifera.

From the hard brown calcareous glauconitic sandstone (bed d, Fig. 14) were collected *Epitonium lyratum* (Zitt.), *Pecten huttoni* (Park) (abundant), *Pachymagas parki* (Hutt.), *Pericosmus compressus* McCoy, and *Cidaris* spines. This bed also yields *Rhizothyris rhizoida* (Hutt.).

DIATOMACEOUS EARTH-DEPOSITS INTERCALATED IN WAIAREKA TUFFS.

Along their western or inland margin, from near Totara to the Waitaki, the Waiareka tuffs are interbedded with two deposits of diatomaceous earth that probably accumulated on the sea-floor during periods of repose from volcanic activity, or during periods when the activity was feeble and its effects limited to the immediate vicinity of the volcanic vents.

The deposits usually occur in two horizons, separated by a variable thickness of tuffs.

The lower deposit is siliceous, the upper usually calcareous. The siliceous deposits consist mainly of diatoms, Radiolaria, and sponge-spicula; the calcareous mainly of diatoms and Foraminifera.

The deposits are not continuous, but occur in flat lens-shaped beds. In some places both the lower and upper beds are present, in other places only the lower is present, and in many places both are absent. At Big Flume Creek there are three diatomaceous horizons.

Good exposures are seen in the face of the escarpment at Kia Ora (the "Jackson's" of former reports), at the old Oamaru stone-quarry west of Round Hill, at Cormack's Siding, at Teaneraki, and Flume Creek near Papakaio.

In the face of the Kia Ora escarpment, almost exactly three-quarters of a mile north-west of Trig. F, there is a lens-shaped deposit of calcareous diatomaceous earth with a maximum thickness of 30 ft. and a linear extension of 300 yards. The upper surface of the deposit is about 20 ft. below the base of the Oamaru stone. Below this deposit, and intimately associated with it, there is a bed of hard fine-grained grey or bluish-grey flaggy siliceous sandstone, which in places shows minute but distinct current-bedding. It contains diatoms and radiolarians. There is some evidence of the occurrence of two beds of siliceous sandstone separated by tuffs, but this is not quite certain, as the scarp-face is obscured by a slope deposit in which blocks of Oamaru stone, diatomaceous earth, siliceous sandstone, and tuff are intermingled. The sandstone seems to consist of fine quartzose sand cemented by the infiltration of siliceous waters. It contains many peculiar tube-like markings that may possibly be fucoid stems.

Below the sandstone there is a flow of columnar basalt, which extends westward to the bank of the Waiareka Stream.

CONFIRMATORY SECTIONS.

Section at old Quarry a Mile South of Round Hill (Trig. K).

At the old stone-quarry the Waiareka tuffs lying below the Oamaru stone are intercalated with a thin irregular lens of impure diatomaceous earth. The section exposed in the quarry-face is shown in Fig. 16.

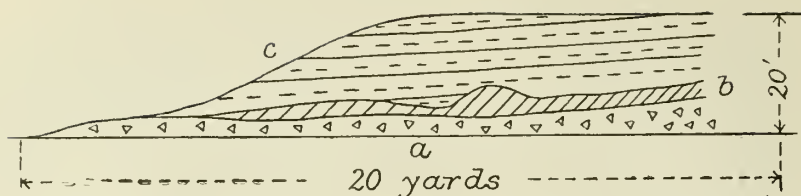


FIG. 16.—SECTION AT OLD QUARRY A MILE SOUTH OF ROUND HILL.

- a. Hard massive dark-grey tuffs formerly quarried for road-metal.
- b. Lens of diatomaceous earth, varying from 0 to 4 ft. thick.
- c. Coarse well-bedded tuffs, tachylitic.

Section at Cormack's Siding.

Beginning at a point about 100 yards west of the railway-siding there is exposed in the north bank of the railway-cutting a deposit of siliceous diatomaceous earth for a distance of 115 yards. The greatest visible thickness of the deposit is 12 ft. The earth is intruded by a sill of basalt; and it lies about 180 ft. below the base of the Oamaru stone. The portion of the deposit richest in diatoms is a light pale-yellowish-grey chalky-like material. In places the diatomaceous material is hard and heavy. Dr. H. A. de Lautour, who devoted much attention to the study of the Miocene diatomaceous earth-deposits of the Oamaru district, considers that the hardness of the heavy material is due to partial fusion through contact with the basalt. The material presents no appearance of fusion, and it seems more probable that the hardness is due to the infiltration of siliceous water. Examination showed that the dense material is poor in diatoms, while the light chalky material is exceedingly rich.

Section in Big Flume Creek, Papakaio.

The deposits of diatomaceous earth occurring at this place are the largest in the Oamaru district. The earth occurs in three horizons in the Waiarekan tuffs (beds *a*, *c*, and *f*, Fig. 17). The relationship of the tuffs to the Oamaru stone is quite clear.

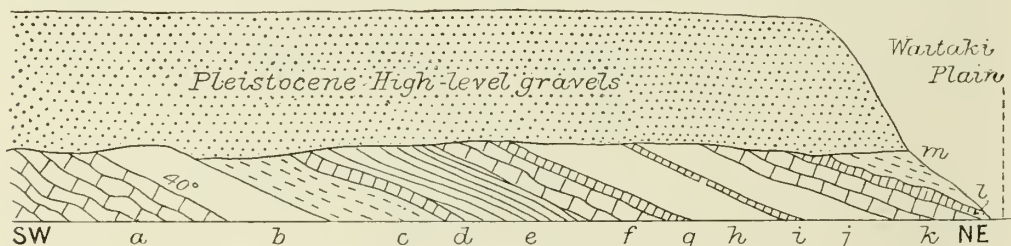
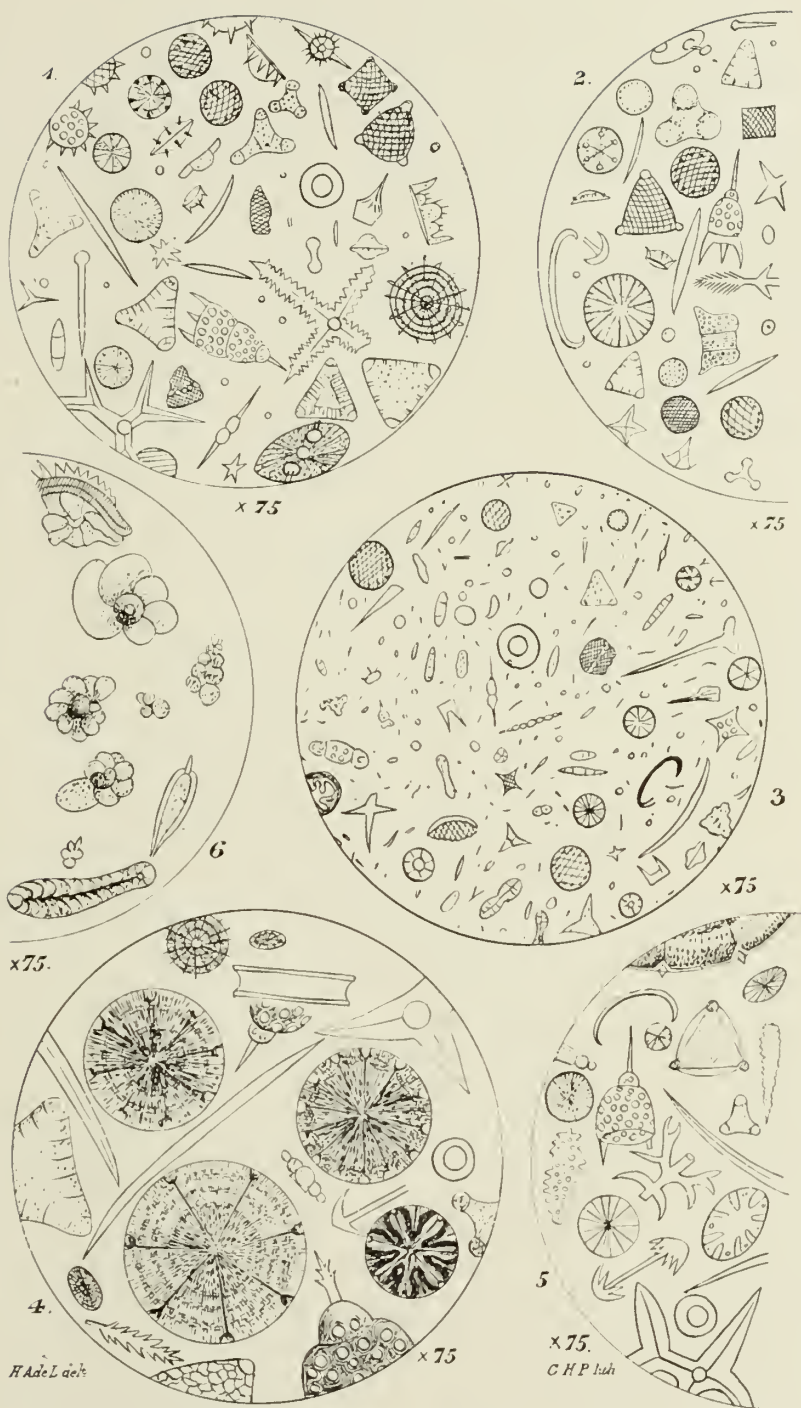


FIG. 17.—SECTION ON NORTH SIDE OF BIG FLUME CREEK.

(Beginning half a mile due east of Trig. H, Papakaio Survey District. Distance, half a mile.)

- a. Grey diatomaceous earth with siliceous muds and sandstones forming hard flaggy layers; 68 ft. showing.
- b. Compact dark-bluish-green tuffs and tufaceous muds, usually siliceous and intensely hard, the lower portion resembling a slaty greywacke; passing upward becomes yellowish-brown and breaks into small cuboidal pieces; texture fine to coarse; 34 ft. thick.
- c. Yellowish-brown tuffs, 40 ft. thick, interbedded with thin deposit of diatomaceous earth
- d. Yellowish-grey calcareous tuffs, 6 ft. thick.
- e. Hard bluish-grey siliceous tuffs, 40 ft. thick.
- f. Diatomaceous earth, impure, siliceous; 25 ft. thick.
- g. Vivid leek-green tuffs, fairly fine texture, 8 ft. thick; upper portion interbedded with flaggy layers of brown calcareous tuff from 5 in. to 8 in. thick.
- h. Mottled brown and green tuffs, 32 ft. thick, with lenses of coarse tachylitic breccia.
- i. Band of hard semi-crystalline limestone, 6 ft.
- j. Yellowish-brown and grey calcareous sandstone, flaky on weathered surfaces, 30 ft. thick, contains layers of glauconitic sandstone ranging up to 4 ft. thick.
- k. Oamaru building-stone, 20 ft. thick.
- l. Bed of hard semi-crystalline limestone, varying from 2 ft. to 9 ft. thick.
- m. Brown or yellowish-brown glauconitic sandstone alternating with hard calcareous layers; thickness unknown; containing *Isis dactyla* Ten.-Woods, *Pecten huttoni* Park, and *Pericosmus compressus* McCoy in lower few feet.

PLATE VI.



OAMARU DIATOMS.

(From *Trans. N.Z. Inst.*, vol. xxi, p. 298, illustrating paper on Oamaru Diatoms by Dr. H. A. de Lautour.)

Fig. 1. Deposit from Cormack's siding.

Fig. 2. Deposit from H. Allen's farm.

Fig. 3. Deposit from Totara Estate.

Fig. 4. Deposit from Jackson's farm.

Fig. 5. Deposit from Bain's highest deposit.

Fig. 6. *Foraminifera* from Jackson's and Bain's.

THE WAIAREKAN DIATOMS.

The richer material is stated by Grove and Sturt to consist mainly of diatomaceous remains, with a small proportion of Radiolaria and sponge-spicula. These authors* described 283 forms of diatoms from Cormack's Siding, of which no less than 107 are new species or varieties. They also discovered four new genera—*Anthodiscus*, *Kiltonia*, *Monopsia*, and *Huttonia*—and a new subgenus—*Pseudo-rutilaria*. In their first paper (*loc. cit.*, vol. ii, Ser. ii, p. 321, No. 16, Sept., 1886) they say there is a remarkable similarity between this deposit and the well-known one at Cambridge Estate, Barbadoes. Several of the forms occurring at Cormack's have hitherto only been met with in the Barbadoes deposit. The family Biddulphiæ, as in the Barbadoes, is strongly represented by the genus *Triceratium*, of which over thirty species or distinct varieties were recognized.

Grove and Sturt also trace a connection between the Simbirsk (Russia) and Cormack's deposits. Several of the species, notably those of *Mastogloia* and *Amphora*, still exist in the Indian Ocean. Figs. 1 to 5, Plate VIII, drawn by Dr. de Lautour, show the characteristic diatoms of deposits at different places near Cave Valley.

In a paper† published in the *Proceedings of the Royal Society of Edinburgh* in 1890, being "A Revision of the Genus *Coscinodiscus* [Ehrb.] and of some Allied Genera," the author, John Rattray, makes many references to the Oamaru diatoms. Among the species he describes as peculiar to the Oamaru deposits are *Coscinodiscus tenuisculptus* Rattray; *C. luctuosus* Grove (MS.), Troublesome Gully, Oamaru; *C. argus* var. *subtrudens* Rattray, and *C. debilis* Rattray, Jackson's Paddock, Oamaru; *C. dubiosus* var. *curvus* Rattray, Troublesome Gully, Oamaru; *C. megacentrum* Grove (MS.), Oamaru; *C. splendidulus* Rattray, Oamaru; *C. decussatus* Grove and Sturt (MS.), Bain's farm, upper stratum, Oamaru; *C. densus* Grove and Sturt (MS.), Oamaru; *Asterolampra uraster* Grove and Sturt, Oamaru; *Liradiscus marginatus* Grove (MS.), Oamaru.

WAIAREKAN SPONGE-REMAINS.

In a paper read before the Linnean Society in 1891‡ G. J. Hinde and W. Murton Holmes described 110 species of siliceous sponges, belonging to forty-three different genera, from the diatomaceous earth-deposits near Oamaru: Monactinellid, seventy species and twenty-four genera; Tetractinellid, twenty-two species and nine genera; Lithistid, seven species and five genera; Hexactinellid, eleven species and five genera.

Referring to the relative abundance of diatoms, sponge-remains, and radiolarians, they say that the material contains such a commixture of these organisms that it could be as appropriately designated after one of these forms of life as after another. They describe the material as greyish-white when dry, soft, earthy, friable, and readily breaking up into a fine mud of a creamy tint when placed in water. The deposit seems to be nearly wholly of organic origin; no sand or other coarse material of mechanical origin could be distinguished in it. Most of the specimens of the material appear to be entirely siliceous, and show no reaction with acid, but in some there is a small proportion of calcareous matter.

In their general summary the authors state that nearly every hitherto known form of spicule of siliceous marine sponges, both skeletal and flesh spicules, is represented in the Oamaru deposit, except some of those from the Palæozoic strata and a few Recent sponges.

* E. Grove and G. Sturt: *Jour. Quekett Micro. Club*, 16th Sept., 1886; 17th Jan., 1887; 18th May, 1887; and 19th Aug., 1887.

† *Proc. Roy. Soc. Edin.*, vol. xvi, 1890, pp. 449–692; with two fold plates.

‡ "On the Sponge-remains in the Lower Tertiary Strata near Oamaru, Otago, New Zealand," *Linn. Soc. Jour.*, Zoology, vol. xxiv, pp. 178–262.

A particular feature of this sponge fauna is the remarkable predominance of the genera and species of Monactinellid sponges over those of other groups.

The nearest existing relatives of many of the sponges in the Oamaru deposits now inhabit the Indian and Southern oceans: some are cosmopolitan in distribution, whilst others as yet have only been recognized in the North Atlantic and the Gulf of Mexico.

Another striking feature is the association of sponge-remains which, as judged by their nearest living representatives, inhabit abyssal depths with others whose relations now live in comparatively shallow water. Thus the Oamaru Tertiary deposit contains numerous spicules of the genus *Hyalonema*, Recent forms of which, according to the "Challenger" Report, usually occur in depths below 1,000 fathoms, and range down to 3,000 fathoms. There are also spicules belonging to such deep-sea Monactinellid genera as *Cladorhiza*, *Chondrocladia*, and *Esperiopsis*, species of which were met with by the "Challenger" at depths from 1,600 to 3,000 fathoms. On the other hand, there are present spicules of such genera as *Myrilla*, which in Recent seas are found in water not more than 10 fathoms deep, and of other genera, both of Monactinellid and Tetractinellid sponges, which now inhabit depths of from 10 to 200 fathoms. This association the authors think may perhaps be explained by the fact that many genera have an extraordinary range in depth—i.e., from 30 to 3,000 fathoms. They think that the Oamaru deposits may be assumed to have been formed at depths of not less than 1,000 to 1,500 fathoms. This assumption, it should be noted, was made in ignorance of the prevailing geological conditions of the deposits. The proximity of the old shore-line, the fact that the Waiarekan tuffs in which these deposits are intercalated rest conformably on the shallow-water quartzose grits and conglomerates of the Ngaparau, and are followed by the Oamaru stone (a shallow-water polyzoan limestone that lies in places not more than 20 ft. above the upper diatomaceous deposits), and the occurrence in the Waiarekan tuffs themselves of shallow-water molluscs and brachiopods, compel us to conclude that the Oamaru diatomaceous deposits are shallow-water deposits probably ranging from 10 to 100 fathoms.

CHAPTER VI.

OTOTARAN STAGE.

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- (a) Kakanui (or Deborah) limestone, in places intercalated with tuffs.
 (b) Upper Oamaru stone } Around Oamaru these
 (c) Kakanui tuffs and breccias, or marly } are replaced by tuffs,
 clays } tachylitic breccias, and
 (d) Lower Oamaru stone } basaltic lava-flows.

GENERAL DESCRIPTION.

THE Ototaran consists of two main subdivisions—namely, the Oamaru stone (the well-known building-stone of that name) and the Kakanui (or Deborah) limestone.

The Oamaru stone is a soft, easily worked polyzoan limestone. In the coastal area it is divided by the Kakanui tuffs and breccias into two unequal portions. The lower is the typical building-stone. The upper is usually tufaceous, and rarely possesses the qualities of a good building-stone. Outside the volcanic zone the Oamaru stone forms a single continuous sheet of good building-material, containing no terrigenous matter.

The Kakanui limestone follows the Oamaru stone conformably. It is mainly polyzoan in structure, and doubtless owes its origin to a continuance of the conditions that gave rise to the Oamaru stone. Hence it may be regarded as a pathological variety of the Oamaru stone. Its hard semi-crystalline character is due to the infiltration of calcareous waters during some change of conditions that took place after its formation.

The uneven and corroded upper surface of the Kakanui limestone was probably due to erosion during an uplift of sufficient extent to bring the surface within the influence of the prevailing coastal sea-currents.

The marine conglomerate which overlies the Kakanui limestone in many places is a record of this period of uplift and erosion.

The Kakanui limestone is persistent throughout the Kakanui Waitaki area, and, except where removed by denudation, is co-existent with the Oamaru stone. It has been distinguished as a submember of the Ototaran on account of its physical characteristics, and the ease with which it can be recognized in the field. Moreover being superior to the Oamaru stone, it represents a correspondingly higher time-plane.

Relationship of Ototaran to Waiarekan.

In some places where the Waiarekan tuffs are well bedded the overlying Oamaru stone is seen to follow them with perfect stratigraphical conformity, as, for example, at Enfield (Fig. 2), Teschemaker's (Fig. 8), Trig. V (Fig. 7), head of Horse Creek (Fig. 13), lower end of Grant's Creek (Fig. 14), and Big Flume Creek (Fig. 17). In other places, as at the Rifle Butts, there is a stratigraphical discordance (Plate IV). This unconformity may be the result of contemporaneous erosion, or perhaps it may have arisen from nearness to the centre of submarine eruption. It is almost certain that as the fragmental volcanic material was ejected it would accumulate around the vent as a broad truncated cone, on the outer slope of which the freshly ejected material would be deposited as layers lying parallel with the slope on which they rested. Whatever the cause of the unconformity, it is certain that it possesses no palæontological significance.

Relationship of Ototaran to Hutchinsonian.

The closing member of the Ototaran is a hard semi-crystalline limestone, more or less phosphatised, lying directly on the Oamaru stone. Where the greensands, the lowest member of the Hutchinsonian, rest on this hard limestone (Deborah or Kakanui limestone) the upper surface of the limestone is usually worn with small shallow basin-like holes, separated by narrow ridges.

The actual contact of the Kakanui limestone and greensands is well seen on the coast at All Day Bay, at the mouth of the north-west branch of Landon Creek (already shown in Fig. 15), and at the Rifle Butts (Plate IV). At Deborah railway-cutting, Hutchinson Quarry, Ardgowan Junction, and Devil's Bridge there is a bed of conglomerate interposed between the Kakanui limestone and the greensands. Except at Devil's Bridge the material composing the conglomerate is basaltic.

From a point half a mile north of Flat Top Hill to the Three Roads the greensands rest on the Kakanui limestone; but at the latter place, as seen in the road-cutting a hundred yards south of the road-junction, the greensands pass from the limestone on to the tachylitic breccia-tuffs (the mineral breccia of Thomson) that underlie the limestone. (See enlarged map of Kakanui area.) It is possible that the stratigraphical unconformity at Three Roads between the greensands and tachylitic breccia may have arisen from volcanic activity at a purely local vent having prevented the spread of the coralline growth to this site. According to the field evidence there is a well-marked stratigraphical unconformity at this place, but, as suggested above, it may be due to some local volcanic happening.

The conglomerate lying between the greensands and the Deborah (Kakanui) limestone is a fairly constant member, being strongly developed at Deborah (Fig. 20), near the Ardgowan Creamery at the junction of Grant's and Oamaru creeks, at Hutchinson's Quarry, along Target Gully, and at Devil's Bridge. At the Devil's Bridge the material composing the conglomerate is a siliceous cement stone; elsewhere it is basaltic. At Deborah, Parson's Creek near Ardgowan Creamery, and Hutchinson's Quarry the conglomerate is glauconitic, and contains marine fossils, among which a thick oyster (*Ostrea wuellerstorfi* Zittel) and the large brachiopod *Terebratulula boehmi* Thomson are nearly always present. The conglomerate, where basaltic, is of marine origin; and

PLATE VII.



James Park, photo]

A. ESCARPMENT OF OAMARU STONE RUNNING SEAWARD FROM TOTARA.



James Park, photo.]

B. RAILWAY-CUTTING SOUTH OF TESCHEMAKER'S RAILWAY-STATION.

the material of which it is composed around Oamaru would indicate that islands or low reefs of volcanic rock existed in this area, and furnished the material. It is possible that the volcanic islands which furnished the basaltic pebbles were piled up by the accumulation of volcanic fragmental material till they became dry land; but it is doubtful if submarine volcanoes would possess the ability to pile up material to a sufficient height and in sufficient bulk to form permanent dry land.

At the Devil's Bridge the Oamaru stone is overlain by a thin sheet of hard siliceous sandstone resembling a quartzite or cement-stone; and the conglomerate which follows is mainly composed of pebbles of this siliceous rock.

The cement-stone conglomerate is continuous, but the sheet of siliceous rock which provided the siliceous pebbles is not continuous. The evidence would seem to indicate that at the Devil's Bridge area, even if not around Oamaru, there was an upward movement of the land at the close of the Ototaran, of sufficient extent to bring the sheet of siliceous rock covering the Oamaru stone under the influence of subaerial erosion for a short interval of time.

At Landon Creek and Waitaki Valley the greensands follow the Oamaru stone conformably, without the interposition of a conglomerate. Clearly, the upward movement did not extend to the Waitaki area, but was confined to the volcanic zone. It was probably the result of local crustal warping arising from volcanic disturbance.

The corroded surface of the limestone at Kakanui and All Day Bay, and the presence of the basaltic conglomerate between the limestone and greensands at Deborah and Oamaru, show that the grouping of the Hutchinson Quarry beds and the Oamaru stone in separate systems, as adopted by the old Geological Survey under Sir James Hector and by Captain Hutton, had some justification on stratigraphical if not on palaeontological grounds. The present survey proves that the stratigraphical break is merely local and of no great moment.

The palaeontological and stratigraphical evidence clearly indicates that the Hutchinsonian is more nearly related to the Awamoan than to the Ototaran. The relationship existing between the Hutchinsonian and Awamoan is generally so close that it is difficult to define where the one ends and the other begins.

OAMARU STONE.

Character of Oamaru Stone.

The typical Oamaru building-stone is a soft grey or pale greyish-yellow polyzoan limestone. It is perfectly free of sand and other mechanically formed detrital matter, and is so soft that it can be sawn into blocks of any desired size and shape with the greatest ease. In places it contains grains of glauconite either scattered throughout the whole mass or occurring in layers. Where the glauconite has become oxidized the stone is stained yellowish-brown.

Isolated examples of molluscs, brachiopods, echinoderms, and fish-teeth occur in the stone, but they are rare.

At Kakanui the Oamaru stone is intercalated with a thick bed of volcanic tuff and breccia that thins out rapidly to the westward and northward. At Totara and Deborah these intercalated tuffs are only a few feet thick, and west of the railway-line soon thin out altogether. The intercalated tuffs to the seaward of the railway-line split the Oamaru stone into two distinct beds, the lower of which is the greater. A mile westward of the railway-line the Oamaru stone occurs as a single sheet. It extends northward from Kakanui to Round Hill, Enfield, Teaneraki, Devil's Bridge, Brockman's Hill, Tabletop Hill, Landon Creek, and Papakaio, altogether a distance of some fourteen miles, with a width varying from one to two miles.

At Fortification Hill and Weston Quarry the Oamaru stone is intercalated with thin tufaceous bands that in places contain brachiopods in great abundance.

The easterly dip of the Oamaruan strata and the great denudation they have suffered on the landward side and along the crown of the Waiareka anticline—the latter a marginal fold in the seaward-dipping strata—have led to the formation of long lines of escarpment crowned by the Oamaru stone. The high escarpment wall between Weston and Enfield, bounding the north-east side of Cave Valley, is a notable example of the effects of subaerial denudation when acting on gently tilted strata surmounted by a hard resistant stratum. Other escarpments occur at Maheno, between Totara and One Tree Hill, between Fortification and Kia Ora, and between Enfield and Teaneraki. Isolated flat-topped outliers like Brockman's Hill and Tabletop Hill are bounded on all sides by steep scarp-faces.

Origin of Oamaru Stone.

The Oamaru stone is the remains of a Middle Cainozoic polyzoan reef that established itself on the submarine platform formed by the eruption of the Waiarekan tuffs. This reef evidently formed a small barrier lying across the ancient Kakanui embayment at a distance of several miles from the old shore-line. As we pass from the present coast towards the ancient strand, across the barrier reef at right angles to its general trend, the limestone is seen to possess a plano-convex transverse section—that is, the platform-floor on which the limestone rests is relatively flat, but to the westward the rock increases from 40 ft. thick at Kakanui to 112 ft. thick near Weston, and thereafter going farther westward and northward thins out altogether.

In the Kakanui-Totara area the renewal of volcanic activity destroyed the marine fauna, whose remains soon became buried beneath a sheet of ash and other volcanic ejecta. When activity ceased Polyzoa once more established themselves, and in course of time built up the upper portion of the Oamaru stone and what is now the Kakanui (or Deborah) limestone. Outside the area affected by this Ototaran volcanic outburst the growth proceeded uninterruptedly and, as stated above, attained a great thickness, the present visible thickness near Weston being 112 ft.

The Kakanui (or Deborah) limestone is the uppermost horizon of the Ototaran. It is co-extensive with the Oamaru stone, on which it rests. Its thickness varies from 2 ft. to 22 ft., this variation arising partly from the effects of denudation. The Kakanui limestone is largely polyzoan, and appears to represent that portion of the "coral reef" that became hard and semi-crystalline through the infiltration of calcareous waters.

Fauna of Oamaru Stone.

The Oamaru building-stone, whether it occurs in a single sheet or in two bands divided by the Kakanui tuffs, consists largely of polyzoan structures. Microscopical examination shows that the calcareous cement filling the interstices is almost wholly made up of Foraminifera, with which also occur Radiolaria and sponge-spicules.

Among the polyzoans and corals identified by Mantell* in the Oamaru stone were *Cereopora ototara*, *Cereopora* sp., and *Manon*, a small claviform species. Those recorded by Tenison-Woods are listed on pp. 116-117.

The Foraminifera† recognized by Rupert Jones include—

Rosalina levigata Ehrenb. Found in chalk of Sicily.

Rosalina beccarii Linn. sp. A common Recent form.

Rosalina sp. Resembling *Cristellaria propinqua* Reuss.

Rosalina lorneiana d'Orb. Cretaceous.

* *Quart. Journ. Geol. Soc. Lond.*, vol. vi, 1850, pp. 329, 330.

† Mantell *loc. cit.*, p. 330.

Textularia sp. Nearly related to a Gault species, and to a species from the magnesian limestone, *T. cuneiformis* Jones.

Textularia elongata. A remarkable species resembling a common form in the Charing chalk-detritus.

Textularia globosa Ehrenb. Common in English chalk.

Textularia aciculata Ehrenb. Common in English chalk.

Globigerina.

Nodosaria } *limbata* d'Orb. Cretaceous.

Cristellaria rotulata Lamk. sp. Cretaceous.

Dentalina.

Polymorphina.

Bulimina. Two or three species.

The echinoderms are represented by the large and distinctive species *Pericormus compressus* McCoy, which ranges throughout the Ototaran and finally disappears at the close of the Hutchinsonian.

The crustaceans in the Oamaru stone recorded by Mantell* include the entomostraceans—

Bairdia subdeltoidea Münster sp. Cretaceous to Recent.

Cythereis interrupta Bosquet sp. Cretaceous.

Cythereis gibba Roemer sp. Tertiary.

Cythereis galtina Jones. Cretaceous.

Among the Mollusca are *Epitonium lyratum* (Zitt.), *Pecten huttoni* (Park), and *Pecten delicatulus* Hutt. A specimen of *Dosinia greyi* Zitt., with both valves complete, was found embedded in a block of Oamaru stone. It was submitted to Mr. Suter, who described it as the largest and finest example of this species, fossil or living, that he had hitherto examined. The valves enclose a hard blue marly clay, and this would tend to show that it had been dropped in its resting-place in the Oamaru coral reef by some bird or fish.

In the Oamaru stone when free from foreign matter the only brachiopod appears to be *Pachymagas parki* (Hutt.), or *P. ellipticus* Thomson, but when tufaceous several genera, each of them usually represented only by a single species, may make their appearance. Those reported by Uttley from the north-west branch of Landon Creek have already been enumerated. The species found by the author in the tufaceous layer in the Oamaru stone at Weston as exposed in the abandoned building-stone quarry near the railway-siding were—

Neothyris uttleyi Thomson (MS.).

Liothyrella pulchra Thomson.

Neothyris tapirina (Hutt.).

Pachymagas parki (Hutt.).

From this tuff band Uttley also collected *Ætheia gaulteri* (Morris), and *Terebratulina oamarutica* Boehm, which is, however, considered to be a synonym of *T. suessi* (Hutt.).

In the lowermost band of calcareous tuff in the Oamaru stone at Fortification Hill, as exposed opposite the south-west corner of the village of Alma, the author collected the following brachiopods:—

Liothyrella pulchra Thomson. *Hemithyris* sp.

Terebratulina suessi (Hutt.).

Terebratella totaraensis Thomson, (possibly the same as *T. kakanuiensis* Hutt.).

* Loc. cit., p. 330.

Section at All Day Bay.

This bay is situated about a mile south of Kakanui South Head. At its north end it is bounded by low rocky cliffs that expose a good section of the volcanic breccias and overlying strata.

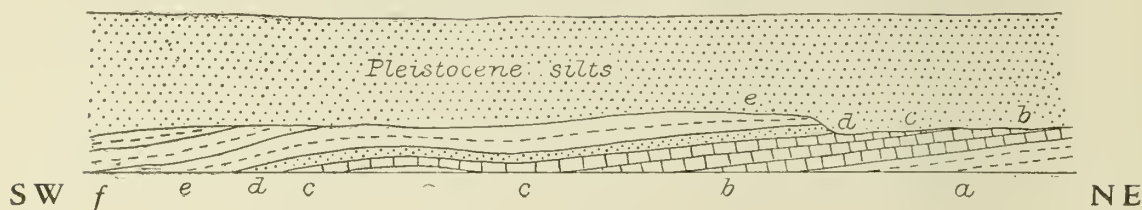


FIG. 18.—SECTION AT NORTH END OF ALL DAY BAY.

- a.* Volcanic breccias and tuffs. *b.* Yellowish-grey polyzoan limestone, 13 ft. thick.
c. Hard semi-crystalline limestone, with upper surface corroded and uneven; 4 ft. thick.
d. Greyish-coloured greensands crowded with *Isis dactyla* Ten.-Woods, and fish-teeth; about 2 ft. thick.
e. Dark greensands with *Pachynagas parki* Hutton in abundance; about 10 ft. thick.
f. Blue marine clays with hard sandstone layers.

In this section beds *a*, *b*, *c*, are Ototaran; beds *d* and *e*, Hutchinsonian; and beds *f*, Awamoan.

The volcanic breccia is well bedded. It forms the whole of the sea-cliffs from the north end of All Day Bay to Kakanui South Head, at the river-mouth. At All Day Bay it dips south-west at an angle of about 8° , but to the northwards, towards the head-land, the inclination increases to 25° , while the strike changes to almost east and west (E. 10° W.), the dip still being to the south. At the mouth of the river the dip is to the north, at an angle of 25° .

The polyzoan limestone (bed *b*) contains a little volcanic ash and some fragments of augite, hornblende, and other minerals. The upper portion of the hard limestone (bed *c*) is glauconitic, and abounds with fossils, mostly as casts. From this bed Uttley collected—

Turbo sp.

Struthiolaria sp.

Polinices oratus (Hutt.).

Cypræa ovulatella Tate.

Epitonium lyratum (Zitt.).

Siphonalia sp. nov.

Cymbiola corrugata (Hutt.).

Euthria media (Hutt.).

Pecten polymorphoides Zitt.

÷ *Lima lima* (L.).

Liothyrella oamarutica (Boehm).

Liothyrella boehmi Thomson.

Terebratulina suessi (Hutt.).

Hemithyris sp., cf. *squamosa* (Hutt.).

Etheia gaulteri (Morris).

The limestones (beds *b* and *c*) are the equivalent of the Kakanui limestone as exposed at the quarry and on the beach north of Kakanui Township.

The lower greensands (bed *d*, Fig. 18) contain the peculiar coral *Isis dactyla* Ten.-Woods in great abundance, *Mopsea hamiltoni* (Thomson), many fish-teeth (mostly those of *Lamna*), and the molluscs *Siphonium planatum* Sut., *Pecten williamsoni* Zitt., and *Teredo heaphyi* Zitt.

The overlying darker and tougher greensands contain the brachiopod *Pachynagas parki* (Hutton) in great numbers, especially in the more sandy lower 2 ft.

The upper surface of the hard limestone (bed *c*) is uneven, having been corroded or worn into smooth cup-shaped depressions that are separated by rounded ridges. The greensands lie on this uneven surface and their lower portion contains hard calcareous

PLATE VIII.



A. C. Gifford, photo.]

A. QUARRY OF OAMARU STONE, TESCHEMAKER'S.



James Park, photo.]

B. GAY'S OAMARU STONE QUARRY, NEAR WESTON.

glauconitic nodules. The surface of the limestone, as well as many of the greensand nodules and numerous *Isis* that occur in the greensands close to the limestone-contact, are covered with a shining yellowish-brown film of tricalcic phosphate. A few widely scattered phosphatic nodules also occur in the upper portion of the greensands (bed *e*). The tricalcic phosphate was obviously deposited by infiltration after the greensands were laid down—perhaps after they were raised above sea-level. Fish and other organic remains are abundant in the greensands, and not improbably these were the source of the phosphoric acid.

Section along South Bank of Kakanui River opposite Kakanui.

The relationship of the volcanic breccia, as exposed at the mouth of the Kakanui, to the rocks that underlie it is shown in the cliffs along the south bank of the Kakanui River from the South Head to a point opposite the village of Kakanui.

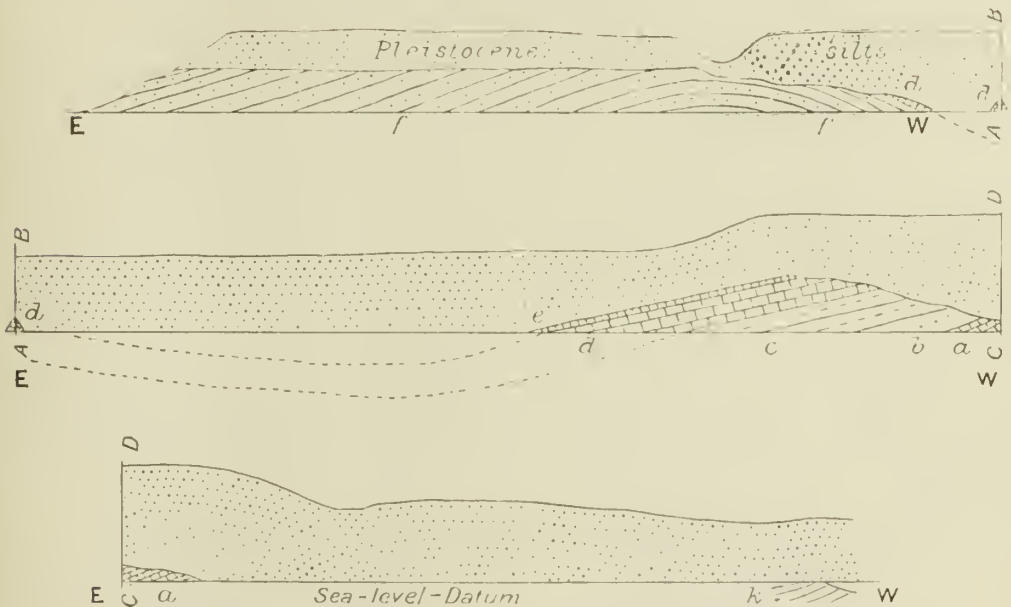


FIG. 19.—SECTION ALONG SOUTH BANK OF KAKANUI RIVER OPPOSITE KAKANUI TOWNSHIP.
(Distance, 800 yards.)

- a.* Thin-bedded yellowish-grey impure limestone; 35 ft. exposed.
- b.* Pale-blue marly clays, interbedded with two bands of hard tufaceous limestone—one at the top of the clays 6 in. to 9 in. thick; the other 4½ ft. lower, 12 in. thick.
- c.* Well-bedded tuffs; angle of dip, from 13° to 14°; strike, N. 10° E.; 58 ft. thick, of which lower 16 ft. is a fine volcanic ash; the upper portion contains fragments of angite, hornblende, garnet, and other minerals in great abundance.
- d.* Yellowish-grey polyzoan limestone; 32 ft. exposed.
- e.* Band of hard flaggy limestone, 4 ft. thick.
- f.* Calcareous tuffs and breccias with minerals; the same rocks as *c.*
- k.* Volcanic breccia.

At point *k*, lying west of the lower limestone (bed *a*, Fig. 19), there is an outcrop of volcanic breccia exposed at low water in the bed of the river. It is distinctly bedded, and dips east at an angle of 10° or 12°. The matrix is fine volcanic ash, and scattered throughout are many angular blocks of vesicular basalt. This fragmental volcanic rock is probably an extension of the Waiareka tuffs, which are strongly developed a short distance to the north of this on the left bank of the Kakanui River and on the same line of strike. The dip of this isolated outcrop of breccia is such as to carry the rock below the lower limestone.

The lower limestone (bed *a*) corresponds to the Oamaru stone. It is a polyzoan limestone containing fine volcanic ash. The thickness exposed in the low shelving bank of the river is 35 ft., but the total thickness is unknown, as the base of the rock is not seen. The upper 6 ft. contains a few scattered molluscs and brachiopods that occur mostly in a fragmentary state or as imperfect casts. Here the author collected a few examples of *Terebratulina suessi* (Hutton): at the same place Uttley found *Liothyrella pulchra* (?) Thomson, and *Liothyrella oamarutica* (Boehm). None of the molluscs collected here by the author could be satisfactorily determined.

The pale-blue marly clays following the lower limestone resemble in appearance and texture the muds erupted around Rotomahana during the Tarawera eruption in 1886. They contain many Foraminifera. Their thickness is about 24 ft. They contain several lines of scattered rounded pebbles of basalt. The presence of these points to the existence of contemporaneous erosion by coastal currents and tides. These clays also contain two thin bands of hard flaggy limestone—one at the top from 6 in. to 9 in. thick, and the other 4½ ft. from the top and about 1 ft. thick.

The fragmental bedded breccia-tuffs that follow the clays are what Thomson* called "mineral breccia." In this report they have been designated the Kakanui tuffs or breccias. They lie between the lower and upper limestones, and form a flat anticline (Fig. 19). The same anticline is seen on the coast a few hundred yards north of All Day Bay—that is, the axis of the anticline passes south-eastward across the promontory of which the South Heads are the extreme east point.

The lower 16 ft. consists of fine dark-brown ash, and the upper 40 ft. of breccias. The latter consist of small angular fragments of basalt, most of them under 3 in. in diameter, set in a matrix of fine calcareous ash, which also contains splinters and fragments of augite, hornblende, and other minerals.

The upper limestone (bed *d*, Fig. 19) is about 32 ft. thick. In its lower portion it contains a good deal of fine volcanic ash, the presence of which renders the limestone soft and friable. It is capped with a band of hard semi-crystalline limestone about 4 ft. thick.

From the tufaceous portion of limestone (bed *d*) Uttley collected—

Epitonium lyratum (Zitt.).

Pecten aldingensis Tate.

Pecten delicatulus Hutt.

Liothyrella oamarutica (Boehm).

Terebratulina suessi (Hutt.).

Magella carinata Thomson.

Hemithyris sp., cf. *squamosa* (Hutt.).

Etheia gaulteri (Morris).

The assemblage of brachiopods and the relationship to the mineral breccia clearly correlate these limestones (beds *d* and *e*) with the limestones exposed at Kakanui lime-kiln and neighbourhood.

CONFIRMATORY SECTIONS.

Sections showing the relationship of the Kakanui (or Deborah) limestone to the overlying greensands are exposed in the railway-cutting near Deborah, at the Devil's Bridge, at lower end of north-west branch of Landon Creek, at the mouth of Big Flume Creek, Papakaio, at Rifle Butts south of Cape Wanbrow and at Hutchinson's Quarry, Oamaru.

Section in Railway-cutting Quarter-mile North of Deborah.

At this place a bed of basaltic conglomerate lies between the limestone and the greensands.

* *Trans. N.Z. Inst.*, vol. xxxviii, p. 486.

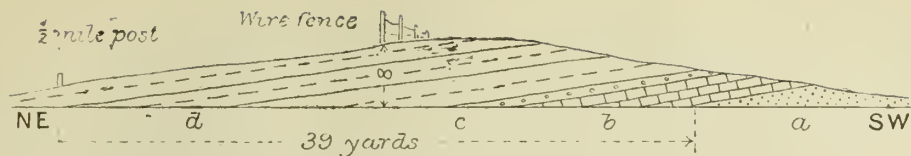


FIG. 20.—SECTION QUARTER-MILE NORTH OF DEBORAH SIDING.

- a. Olive-green tuffs, with splinters of garnet, augite, &c.; base not seen. c. Basaltic conglomerate, glauconitic and calcareous.
 b. Hard semi-crystalline limestone; lower portion glauconitic, coralline, and soft; 11 ft. thick. d. Greensands crowded with *Pachymagas parki* Hutt.; also contains many molluscs.

These beds dip almost north-east (true) at an angle of 18°. Beds *c* and *d* belong to the Lower Hutchinsonian stage.

At the south end of the railway-cutting the tuffs are underlain by the Oamaru stone, and at the old quarry 400 yards due south of the Deborah railway-siding the tuffs are seen lying between the Oamaru stone and Deborah limestone. Here they are 11 ft. thick, and, as elsewhere, contain splinters of garnet, augite, hornblende, and other minerals.

The base of the Deborah limestone (bed *b*) is a soft impure iron-stained glauconitic limestone composed mainly of corals, bryozoans, and Foraminifera, mingled with some fine volcanic ash which is chiefly responsible for the friable character of the rock. Besides corals there are present echinoderm spines and plates in great abundance, as well as some scattered molluscs, mostly fragmentary, and a few brachiopods, the latter including *Liothyrella oamarutica* (Boehm) and *Terebratulina suessi* (Hutt.).

The conglomerate consists mainly of well-rounded basaltic pebbles set in a calcareous glauconitic greensand matrix. The lower 6 ft. of the greensands contain many molluscs and brachiopods. Above that the greensands are crowded with *Pachymagas parki* (Hutt.), and molluscs are relatively scarce. Among the molluscs collected in the lower 8 ft. of the greensands were, —

- | | |
|---|------------------------------------|
| <i>Epitonium</i> n. sp. | <i>Cardium spatiosum</i> (?) Hutt. |
| ± <i>Xenophora corrugata</i> (Reeve). | <i>Lima colorata</i> Hutt. |
| <i>Turritella concava</i> (?) Hutt. | <i>Lima paleata</i> Hutt. |
| ± <i>Siphonalia dilatata</i> (Q. & G.). | <i>Mastra attenuata</i> Hutt. |
| <i>Teredo hepaphyi</i> Zitt. | <i>Panope worthingtoni</i> Hutt. |
| <i>Sirantholaria tuberculata</i> Hutt. | <i>Pecten beethami</i> Hutt. |
| <i>Dentalium solidum</i> Hutt. | <i>Pecten hutchinsoni</i> Hutt. |
| <i>Cymbiola corrugata</i> (Hutt.). | <i>Pecten huttoni</i> (Park). |
| <i>Fusinus solidus</i> (?) Sut. | <i>Pecten semiplicatus</i> Hutt. |
| <i>Cardium patulum</i> (?) Hutt. | <i>Protocardia sera</i> Hutt. |

From the same portion of the greensands Uttley collected *Pecten triphaeki* Zitt., *Pecten delicatulus* Hutt., *Ætheia gaulteri* (Morris), *Terebratulina suessi* (Hutt.) *Isis dactyla* Ten-Woods, and *Mopsea hamiltoni* (Thomson).

Section at Hutchinson's old Quarry, Lower End of Target Gully, Oamaru.

Though an isolated outcrop, this old quarry has figured so largely in the geological literature of Otago that it has become classical. Here an unknown thickness of tuffs is succeeded by an impure limestone consisting of irregular layers of pure fine-grained limestone separated by layers of tuff. Overlying the limestone comes a thick bed of basaltic conglomerate, and over this are greensands. The latter are interbedded in their upper portion with bands of hard calcareous brown glauconitic sandstone. These hard bands weather out on the hillside as overhanging cornices, and they may be traced as a chain of disconnected outcrops along the north slope of Target Gully, from Hutchinson's Quarry to a point near the Oamaru Borough reservoir, a distance of nearly two miles.

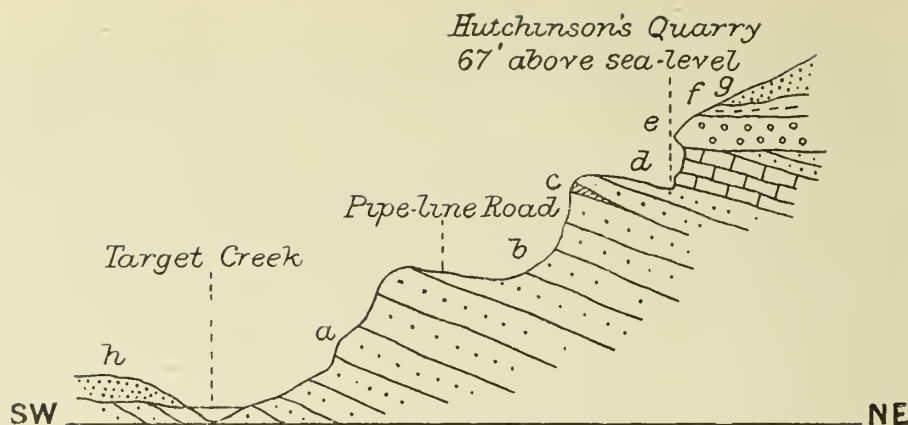


FIG. 21.—SECTION AT HUTCHINSON'S QUARRY, EDEN STREET, OAMARU.

(Horizontal scale 40 ft. = 1 in. ; vertical scale, 20 ft. = 1 in.)

- a.* Greenish-brown bedded tuffs, with blocks of vesicular basalt. *b.* Mottled yellow and red tuffs.
c. Fine-bedded yellow and purple tuffs, with thin irregular bands of hard fine-grained limestone.
d. Hard flaggy fine-grained limestone, with irregular lenses and bands of tuff, in places glauconitic; 6 ft. thick.
e. Basaltic conglomerate, calcareous, 8 ft. thick.
f. Glauconitic greensands, fossiliferous, with *Pachymagas parki* in great abundance.
g. Slope clays and silts. *h.* Yellow silts.

The limestone, as well as the irregular layers of tuff in the limestone, contain fine splinters of black minerals. The limestone is in places so fine-grained as to resemble lithographic stone. It contains fossils, but no recognizable forms could be extracted, on account of the hardness and shattered condition of the rock.

The strike of the beds, so far as can be judged from the short exposure (Plate X), is about north-west-south-east. The dip is about north-east (true), at angles varying from 12° to 17° .

The conglomerate is about 8 ft. thick, and consists of rounded and semi-rounded pebbles of basalt set in a calcareous tuff matrix. Some angular pieces of basalt are also present. At the base of the conglomerate, and resting on the inclined edges of the tufaceous limestone (bed *d*), there is a thin horizontal bed of fine lithographic limestone, varying from 1 in. to 6 in. thick.

Some 8 or 10 yards south of the old quarry excavation the conglomerate is faulted down to the level of the limestone by a small fault, which is seen a few yards behind the overhanging ledge of conglomerate, as shown in Fig. 22.

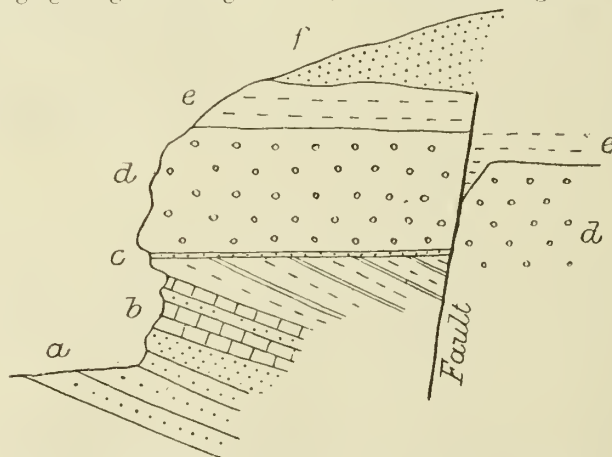


FIG. 22.—ENLARGED SECTION OF HUTCHINSON'S QUARRY.

- a.* Yellowish-red and purple tuffs with limestone lenses. *d.* Basaltic conglomerate, 8 ft. thick.
b. Hutchinson Quarry limestone and tuffs. *e.* Glauconitic greensands, fossiliferous.
c. Horizontal band of limestone, from 1 in. to 6 in. thick. *f.* Surface clays and silts.

The thickness of greensands as exposed 9 yards south of the quarry excavation is about 18 ft. The lower 12 ft. consists of greyish-coloured glauconitic greensands crowded with *Pachymagas parki* (Hutt.) and *Rhizothyris rhizoida* (Hutt.). They also contain many molluscs, echinoderm spines and plates, corals, and cup-shaped bryozoans. The claws of a powerful crab, *Balanus* plates, fragments of cetacean bones, and fish-teeth are also present.

The molluscs collected from these greensands (Lower Hutchinsonian stage) include--

<i>Ancilla papillata</i> (Tate).	<i>Pecten hutchinsoni</i> Hutt.
<i>Polinices gibbosus</i> (Hutt.).	<i>Pecten beethami</i> Hutt.
<i>Polinices huttoni</i> von Iher.	<i>Pecten radiatus</i> Hutt.
<i>Polinices ovatus</i> (Hutt.).	<i>Pecten semiplicatus</i> Hutt.
<i>Ampullina suturalis</i> (Hutt.).	<i>Pecten yahliensis</i> Ten.-Woods.
<i>Dentalium solidum</i> Hutt.	<i>Lima colorata</i> Hutt.
<i>Epitonium lyratum</i> (Zitt.).	<i>Lima paleata</i> Hutt.
<i>Siphonium planatum</i> Sut.	<i>Lima lavigata</i> Hutt.
<i>Cucullaea alta</i> Sow. Cast.	<i>Ostrea ruellerstorfi</i> Zitt.
<i>Diplodonta globularis</i> (Lam.). Cast.	<i>Panope orbita</i> Hutt. Casts.
<i>Chione meridionalis</i> (Sow.).	<i>Paphia curta</i> (Hutt.).
<i>Crassatellites obesus</i> (A. Ad.).	<i>Protocardia pulchella</i> (Gray). Cast.
<i>Glycymeris cordata</i> (!) (Hutt.).	<i>Protocardia sera</i> Hutt. Casts.
<i>Glycymeris laticostata</i> (Q. & G.).	<i>Venericardia purpurata</i> (Desh.).
<i>Limopsis zitteli</i> von Iher.	<i>Venericardia psentes</i> Sut.
<i>Pecten huttoni</i> (Park).	

The upper portion of the greensands consists of dark-green glauconitic sands that seem to contain no fossils at this place. They are obscured by a heavy slope deposit, hence their thickness is unknown. Tumbled blocks of a hard brown calcareous sandstone, which is seen farther up Target Gully overlying the greensands on the same slope, occur at Hutchinson's Quarry, and must be present *in situ* a little higher up the hill. This sandstone band contains the casts of many shells, among them that of *Pachymagas parki* (Hutt.). On the Town Belt, farther up Target Gully, the upper portion of the greensands underlying the Awamoan shell-bed is richly fossiliferous.

Section at Devil's Bridge.

The rocks represented at this place are the Oamaru stone and the greensand series of beds. At the base of the greensands there is a thin sheet of conglomerate composed of well-rounded pebbles of siliceous cement-stone. Below this, as seen at the outlet end of the Devil's Basin near the natural bridge, the Oamaru stone is covered with a thin bed of siliceous cement-stone varying from 6 in. to 12 in. thick. On the lower side of the natural bridge the Oamaru stone is followed by a band of hard semi-crystalline limestone from 2 ft. to 4 ft. thick. This band increases in thickness towards Brockman's Hill, and at a point half a mile north-west of the Devil's Bridge forms a conspicuous rocky ridge.

At the Devil's Bridge the Oamaru stone is about 80 ft. thick. At the outlet from the Devil's Basin its strike is N. 35° E., and the dip south-east at angles ranging from 18° to 21°.

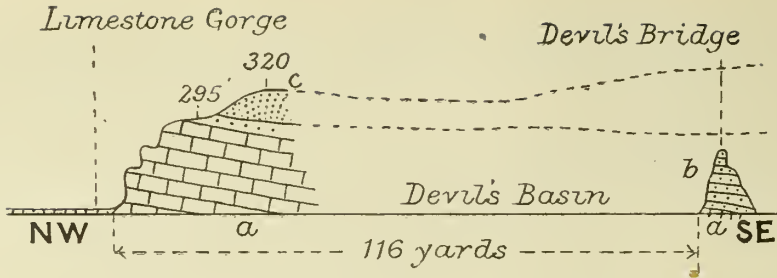


FIG. 23.—SECTION ACROSS DEVIL'S BASIN.

a. Oamaru stone. b. Greensands, &c. c. Pleistocene silts.

A diagrammatic sectional view of the cliff-face at the outlet end of the Devil's Basin at the natural bridge is shown in Fig. 24.

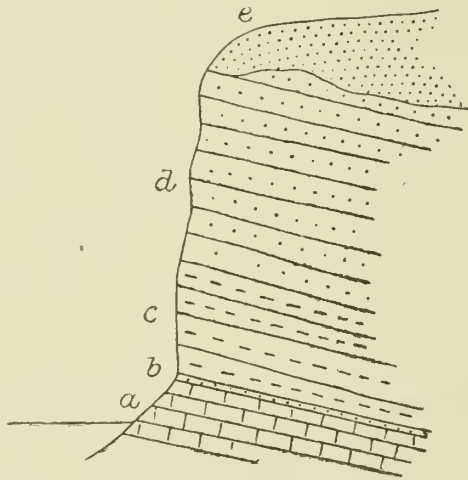


FIG. 24.—SECTION AT OUTLET END OF DEVIL'S BASIN.

- a. Oamaru stone through an underground passage in which the stream flows.
 b. Band of siliceous conglomerate from 6 in. to 12 in. thick.
 c. Soft friable glauconitic sandstone, 12 ft. thick, crowded with *Pachymagas parki* (Hutt.), especially the lower few feet above the conglomerate.
 d. Brown calcareous glauconitic sandstone, 30 ft. thick, in places rich in molluscs. e. Pleistocene silts.

The greensand-beds (c, Fig. 24), besides *Pachymagas parki*, contained *Rhizothyris rhizoida* (Hutt.), *Pecten huttoni* (Park), and *Pecten beethami* Hutt., the last two in considerable abundance.

From the glauconitic calcareous sandstone forming the natural bridge were collected many molluscs, including—

÷ *Calyptæa maculata* Q. & G.
Turritella concava Hutt.
Turritella semiconcava Sut.
Teredo hepaphyi Zitt.
Emarginula wannonensis Harris.
÷ *Ampullina undulata* (?) Hutt.
Astarte australis Hutt.
Chione meridionalis (Sow.)
÷ *Crassatellites obesus* (A. Ad.).

Cucullæa alta (?) Sow.
Lima colorata Hutt.
Lima paleata Hutt.
Pecten huttoni (Park).
Pecten beethami Hutt.
Pecten yahliensis Ten.-Woods.
÷ *Venericardia purpurata* (Desh.).
Venericardia pseutes Sut.

Sections in Landon Creek, Main Branch, Papakaio.

The Oamaru stone and overlying greensands and glauconitic sandstone of the Hutchinsonian are well exposed along the course of Landon Creek. in the low cliffs that form the walls of the narrow gorge through which this stream flows in the upper portion of its course. On the banks of the stream, at a point a little less than half a mile above the junction of the west branch and one mile due west of Trig. B, we have the section shown in Fig. 25.



FIG. 25. SECTION IN LANDON CREEK, ABOUT HALF A MILE ABOVE THE JUNCTION OF THE WEST BRANCH.

- a. Oamaru stone, 8 ft. exposed.
- b. Brown calcareous glauconitic sandstone, fossiliferous, 6 ft. thick.
- c. Nodular greensands, $4\frac{1}{2}$ ft. thick, with many brachiopods.
- d. Rusty-brown glauconitic greensands crowded with *Pachymagas parki* Hutt.; also contains *Pecten huttoni* Park, *P. beethami* Hutt., and *P. hutchinsoni* Hutt., besides many corals, cup-shaped bryozoans, and echinoderm spines: thickness exposed, 15 in.

From bed c were collected—

<i>Ætheia gaulteri</i> (Morris).	<i>Pachymagas ellipticus</i> Thomson.
<i>Terebratulina suessi</i> (Hutt.)	<i>Pachymagas parki</i> (Hutt.).
<i>Liothyrella landonensis</i> Thomson.	<i>Rhizothyris rhizoida</i> (Hutt.).
<i>Liothyrella</i> sp.	<i>Hemithyris depressa</i> Thomson.
<i>Neothyris tapirina</i> (Hutt.).	

From what seems to be the same bed Uttley also collected *Liothyrella boehmi* Thomson, and the coral *Isis dactyla* Ten.-Woods.

A quarter of a mile higher up the stream, at the lower end of the gorge, a good section is exposed on the east bank.

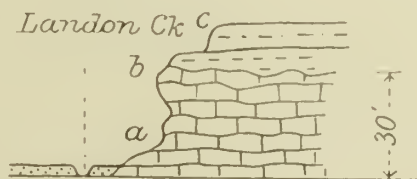


FIG. 26. SECTION ON EAST SIDE OF LANDON CREEK.

Ototaran	a. Oamaru stone, 30 ft. showing.
Hutchinsonian	b. Brown glauconitic sandstone, 5 ft. thick; the same as bed b in Fig. 25; fossiliferous.
	c. Hard nodular greensands.

The higher portion of the Oamaru stone is glauconitic and tufaceous, and its upper surface along the contact with bed b is corroded and uneven. The actual contact is occupied by a limonitic rubbly layer, varying from 3 in. to 9 in. thick. This layer contains scattered water-worn quartz pebbles. It is fossiliferous, most of the fossils being polyzoans, echinoderm spines, and brachiopods. The latter included *Ætheia gaulteri* (Morris) and *Pachymagas* sp.

Still higher up the gorge, at the north end of the wooden flume across Landon Creek, the calcareous glauconitic sandstone expands to a visible thickness of 24 ft.

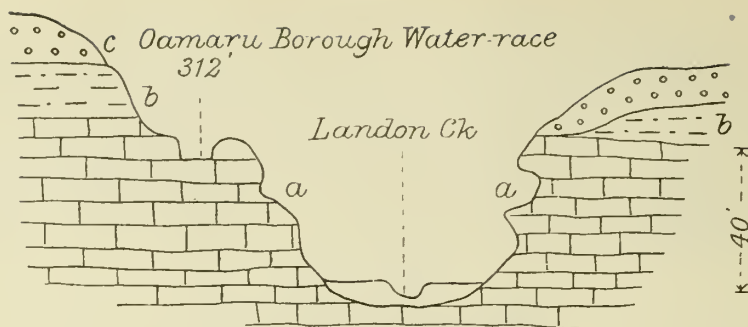


FIG. 27 SECTION ACROSS LANDON CREEK GORGE AT NORTH END OF FLUME CARRYING OAMARU BOROUGH WATER-SUPPLY.

Ototaran	a. Oamaru stone, 40 ft. showing.
Hutchinsonian	b. Glauconitic sandstone, 24 ft. showing.
Pleistocene	c. High-level gravels.

From the lower portion of the glauconitic sandstone were collected the brachiopods *Liothyrella landonensis* Thomson, *Pachymagas parki* (Hutt.), and *Hemithyris* sp., and the molluscs

÷ <i>Epitonium zelebori</i> (Dkr.).	<i>Pecten huttoni</i> (Park).
÷ <i>Pecten beethami</i> Hutt.	<i>Pecten semiplicatus</i> Hutt.
<i>Pecten burnetti</i> Zitt.	÷ <i>Crassatellites obesus</i> (A. Ad.).
<i>Pecten hutchinsoni</i> Hutt.	<i>Chione meridionalis</i> (?) (Sow.).

Echinoderm-remains, corals, and bryozoans are present in great abundance in this horizon.

Section at Brockman's Hill.

At this place the Waiareka tuffs are followed by tufaceous calcareous strata, which are overlain by the Oamaru stone which crowns the hill. The succession of rocks is,—

- (a.) Waiareka tuffs, of which a thickness of over 200 ft. are exposed; near the road-level intruded by basaltic dykes.
- (b.) Grey and yellowish-brown calcareous tuffs, in places passing into an impure polyzoan limestone; also contains bands of hard semi-crystalline limestone that are brecciated with angular fragments of basaltic material.
- (c.) Yellowish, grey, or brown calcareous sandstone, slightly tufaceous; 24 ft. thick.
- (e.) Oamaru stone, 28 ft. thick.

Bed *b* contains molluscs, brachiopods, and many Polyzoa. The brachiopods identified here were *Terebratulina suessi* (Hutt.), *Neothyris tapirina* (Hutt.), and *Ætheia gaulteri* (Morris).

Among the molluscs from here were *Ostrea incurva* Hutt., with borings of *Pholadidea* (*P. thomsoni*?), *Panope* sp., and *Teredo hepaphyi* Zitt.

Section at Tabletop Hill.

This hill lies half a mile north of Brockman's Hill. It is composed of Waiareka tuffs, which are surmounted by the calcareous Ototaran strata. The rocks represented at the summit of the hill are,—

- (a.) Waiareka tuffs.
- (b.) Soft or moderately hard yellowish-brown calcareous tuffs, mainly composed of comminuted corals and shells; 12 ft. thick.
- (c.) Soft yellowish-brown calcareous sandstone; 24 ft. thick.
- (d.) Hard yellowish-brown calcareous sandstone occupying the summit of the hill; breaks up into large tabular masses; from 2 ft. to 5 ft. exposed.

At the east side of the hill bed *c* is interbedded with a band of typical Oamaru stone 4 ft. thick, which thins out rapidly and disappears before the west side of the hill is reached. This is the last appearance of the Oamaru stone to the westward.

From bed *b* were collected the following (all young shells):—

<i>Placunanomia incisura</i> Hutt.	÷ <i>Lima angulata</i> Sow.
<i>Limopsis catenata</i> Sut.	÷ <i>Lima bullata</i> (Born).
<i>Pecten aldingensis</i> Tate.	÷ <i>Venericardia difficilis</i> (Desh.).
<i>Pecten delicatulus</i> Hutt.	<i>Chione meridionalis</i> (?) (Sow.).

Section at Lower End of West Branch, Landon Creek.

This section has already been described (page 16), and the relationship of the Ototaran to the Hutchinsonian illustrated by Fig. 15.

The actual contact of the greensands and the hard semi-crystalline limestone band which covers the Oamaru stone is obscured by black soil and grass. Though there seems to be no conglomerate bed at the base of the greensands, it is quite certain from what can be seen that the upper surface of the hard limestone is broken, nodular, and glauconitic. It was in this nodular portion that the fine brachiopod *Liothyrella landonensis* Thomson was found.

Section in Waitaki Valley at Lower End of Big Flume Creek, on South-east Side of Flume, South-east of Papakaio Railway-station.

This section is important, as it shows not only the relationship of the Oamaru stone to the Hutchinsonian, but also—what is of greater significance—the relationship of the Oamaru stone to the Waitaki stone.

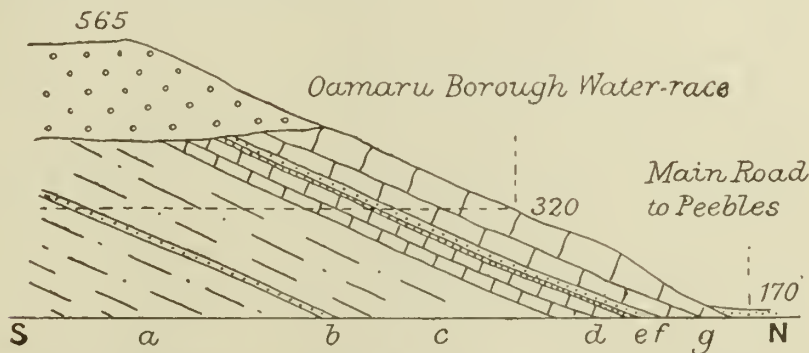


FIG. 28.—SECTION IN WAITAKI VALLEY AT MOUTH OF BIG FLUME CREEK, SOUTH-EAST SIDE.

- a. Mottled brown and green tuffs with calcareous layers; contain scattered blocks of vesicular basalt up to 6 in. in diameter, also splinters and broken crystals of dark-coloured augite, &c.
- b. Bed of coarse tuff, 12 in. to 18 in. thick, with widely scattered angular blocks of vesicular basalt.
- c. Mottled brown and green tuffs, much like *a*.
- d. Oamaru stone, 14 ft. thick; typical building-stone.
- e. Band of hard grey semi-crystalline limestone, 4 ft. thick.
- f. Glauconitic sandstone, 2 ft.; crowded with *Isis dactyla* Ten.-Woods, and *Cidarid* spines.
- g. Glauconitic sandstone; fossiliferous; 26 ft. exposed; throughout alternates with thin flaggy bands of harder calcareous glauconitic sandstone. These bands are often nodular and irregular. In all cases the harder materials weather out as distinct projecting ledges.
- h. High-level Pleistocene gravels.

The strike of the beds at this place is east-north-east—west-south-west, and the dip north-north-west at an angle of 17° or 18°.

The glauconitic sandstone *g* alternating with hard calcareous layers is bed *m* of Fig. 17. It forms high bluffs and cliffs, and is the typical Waitaki stone that overlies the greensands and forms long lines of escarpment a few miles farther up

the Waitaki Valley. Fossils are fairly abundant but difficult to extract. Among these collected from bed *f* and lower portion of *g* were.—

<i>Balanus</i> sp.	<i>Pachymagas parki</i> (Hutt.).
<i>Pecten huttoni</i> (Park).	<i>Ætheia gaulteri</i> (Morris).
<i>Pecten polymorphoides</i> Zitt.	<i>Terebratulina suessi</i> (Hutt.).
<i>Pericosmus compressus</i> McCoy.	

Besides containing *Isis dactyla* Ten.-Woods in great abundance, the lower few feet of the glauconitic sandstone (bed *f*) also contains *Mopsea hamiltoni* (Thomson) and *Flabellum* sp.

If the beds are arranged in stages we get, in ascending order—

Ototaran ..	(a) Mottled brown and green tuffs	} Kakanui mineral tuffs.
	(b) Coarse tuff	
	(c) Mottled brown and green tuffs	
	(d) Oamaru stone (upper band).	
	(e) Hard grey semi-crystalline limestone = Deborah (or Kakanui) limestone.	
Hutchinsonian	(f) Glauconitic sandstone with <i>Isis dactyla</i> (= greensands).	
	(g) Glauconitic sandstone with hard calcareous flaggy layers (= Waitaki stone).	

KAKANUI TUFFS AND BRECCIAS.

It has already been recorded that in the area lying east of the Dunedin-Oamaru railway-line the Oamaru stone is intercalated with coarse tuffs and mineral breccias, which attain their greatest thickness on the coast near Kakanui, and rapidly thin out to the westward. The accumulation of these fragmental volcanic rocks was sufficiently slow to permit the marine fauna in the adjacent sea to migrate into this area. Hence it happens that in these inter-Oamaru stone tuffs and breccias in this area we have an assemblage of the contemporary molluscan life of the Oamaru stone horizon.

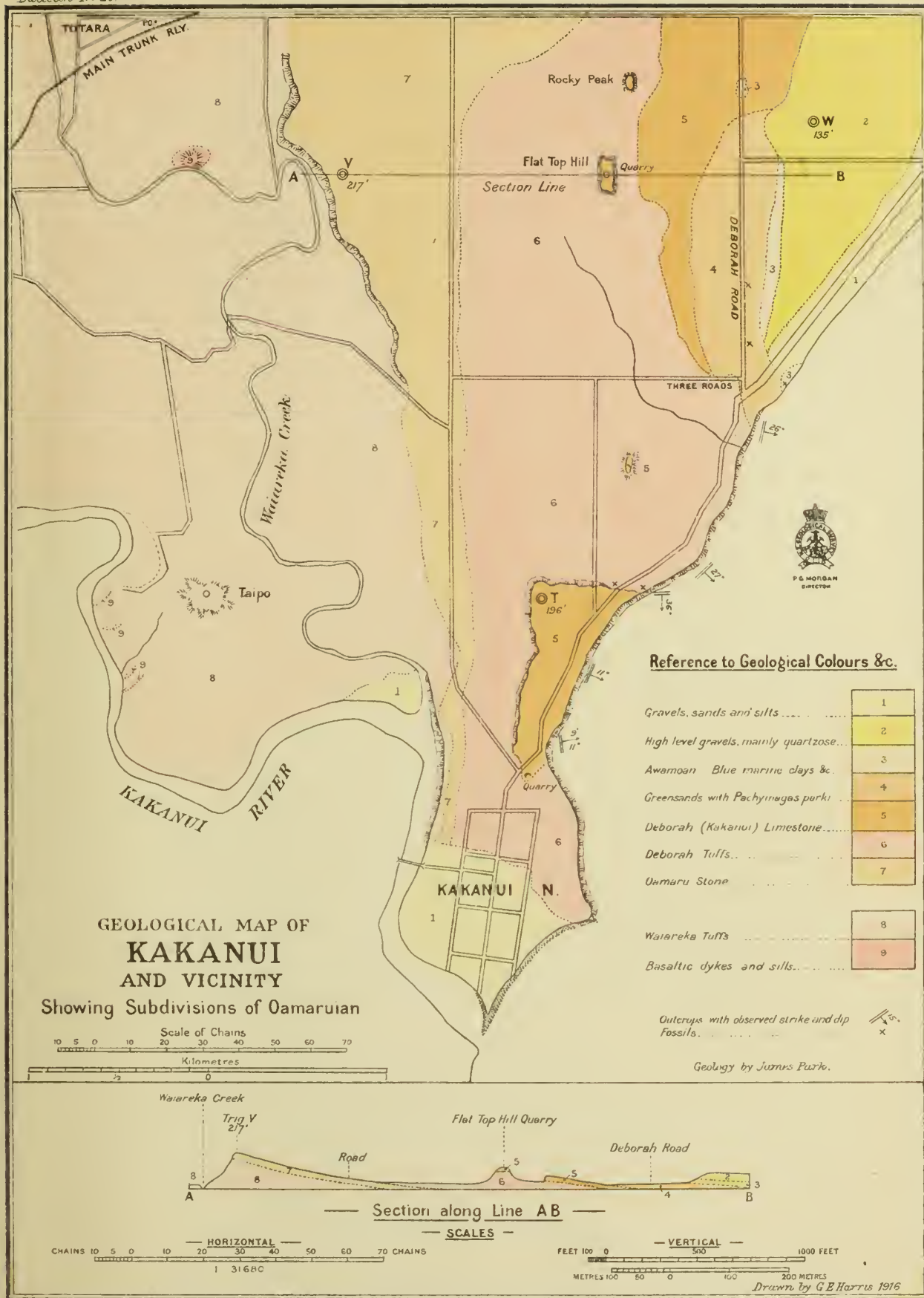
The greatest development of these Ototaran tuffs and breccias is on the coast about a mile north of Kakanui. Westward of this the volcanic fragmental material thins out rapidly, and at Teschemaker's, Totara, and Deborah is only a few yards thick. At Weston Quarry, which is less than two miles north-west of the main railway-line, the tuffs have dwindled to a few feet; while at Gay's Quarry, a mile north of Weston, there is no volcanic material in the Oamaru stone. The fragmental material from the Kakanui volcano does not appear to have reached west of Totara, north-west of Weston, or north of Grant's Creek.

In the Papakaio area of the lower Waitaki Valley the Oamaru stone is also intercalated with a great thickness of fragmental volcanic material (Fig. 17) containing many of the minerals found in the Kakanui tuffs. These tuffs were probably emitted by an independent submarine volcano that became active about the same time as the Kakanui volcano. The material ejected by the Papakaio volcano, as exposed in Big Flume Creek, contains no trace of organic remains.

The Kakanui volcanic breccia is strongly developed at Kakanui South Head (Fig. 19), Kakanui North Head, and on the coast from a mile to two miles north of Kakanui. Thomson* estimates the minimum thickness at the North Head at 130 ft. On the coast north of Kakanui the thickness is not less than 150 ft., and may be much greater.

At the North and South Heads the breccia consists of rudely bedded coarse angular tachylitic material, set in a matrix of volcanic ash cemented by carbonate of

* J. A. Thomson: "The Gem Gravels of Kakanui; with Remarks on the Geology of the District." *Trans. N.Z. Inst.*, vol. xxxviii, 1906, pp. 482-495; 4 figs.



lime. On the coast north of Kakanui the coarser tachylitic material gives place to finer ash, usually well bedded and often brecciated with angular fragments and blocks of vesicular basalt. To the westward the material becomes thinner and finer in texture, though it occasionally contains coarser layers, as at Trig. M, south-east of Sebastopol.

At Kakanui Quarry, also on the beach below that quarry, on the beach below Trig. T, on the coast two miles north of Kakanui, at Flat Top Hill, and in the road-cuttings half a mile east of that hill the Kakanui tuffs and breccias are fossiliferous in their upper portion. At Teschemaker's, Totara, Trig. M, and Weston Quarry, where they are only a few yards thick, fossils abound throughout.

At Kakanui Quarry and in the road-cuttings half a mile north of Flat Top Hill the tuffs contain a lens or thin irregular sheet of well water-worn basaltic material that occurs as the uppermost member—that is, it lies immediately below the upper band of Oamaru stone, and is usually fossiliferous.

Almost everywhere the Kakamui tuffs and breccias contain angular splinters and cleavage pieces of many minerals, and in the vicinity of Kakanui also include fragments of rocks of many kinds. The presence of the minerals was noted by Walter Mantell* in 1849. Afterwards they were referred to by Ulrich, Hutton, Hector, McKay, and Thomson. The only systematic study of these minerals was that undertaken by Thomson in 1905, the results being embodied in his paper on "The Gem Gravels of Kakanui," previously referred to. The minerals identified by Thomson† were—Black augite, hornblende, feldspar (near oligoclase), in large fragments; garnet, diopside, diallage, biotite, olivine, smaragdite, in small fragments. Among the rocks identified by him were: Basalt; sandstone, limestone, greywacke; quartz, mica-schist, granulite, and garnet-gneiss; various basic plutonic rocks, which may be grouped in two classes—(1) lherzolites, eulysites, and wehrilite (containing fine spinels), (2) garnetiferous peridotites.

The basalt, he says, contains inclusions of almost all the other rocks and minerals found in the breccia.

The crystalline rocks were no doubt torn from the walls of the vent during the upward rush of the volcanic ejecta. Their presence in the breccias is a proof of their existence below the Cainozoic strata in the coastal area around Oamaru. They are probably the basal rocks of this region.

The Kakamui tuffs and breccias are in most places followed conformably by the upper band of Oamaru stone, which is usually tufaceous and varies from a few inches to 10 ft. thick. In a few places a bed of fine marly clays lies between the breccias and the upper limestone, as on the beach immediately below the Kakanui lime-kiln. These marly clays appear suddenly and disappear suddenly. Their lens-shaped form and their irregular distribution suggest that they are tongues of volcanic mud that gathered on the slopes of the tuff-cone.

Fauna of Kakanui Tuffs and Breccias.

The upper portion of this fragmental deposit contains a large assemblage of molluscs—an assemblage which bridges over the puzzling hiatus that seemingly existed between the molluscan faunas below and above the Oamaru stone. The faunas below and above the Oamaru stone were long recognized to contain many features in common, and were by some thought to be the same. We now know that they differ, though related in many features, the inter-Ototaran fauna forming the connecting-link.

* *Quart. Jour. Geol. Soc. Lond.*, vol. vi, 1850, p. 325.

† *Loc. cit.*, p. 492.

Besides many molluscs, brachiopods are numerous, as well as corals, bryozoans, and Foraminifera. The remains of a whale, probably *Kekenodon*, and the teeth of *Carcharodon* and *Lamna*, are also found in these fragmental volcanic rocks.

Section, Kakanui Lime-quarry to the Sea.

From Kakanui Quarry the outcrop of the Kakanui limestone and underlying tuffs runs north to Trig. L, a distance of three-quarters of a mile. The dip of the limestone is east—that is, towards the sea. From the quarry northward half a mile the limestone forms the sea-cliffs, the trend of the coast in this stretch running parallel with the strike.

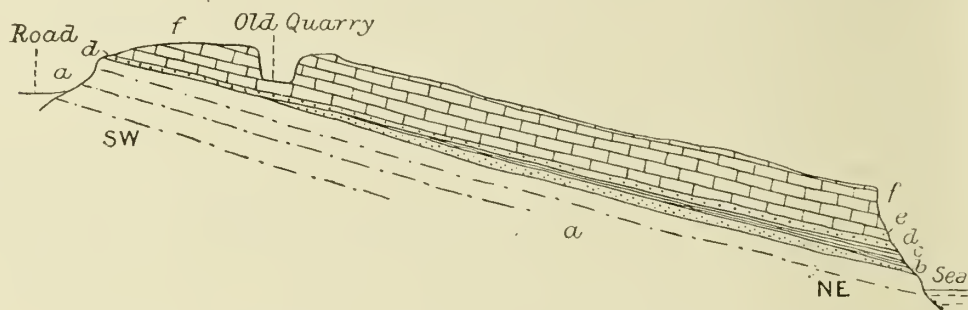


FIG. 29.—SECTION FROM NEAR KAKANUI QUARRY NORTHWARD TO THE SEA

- a. Kakanui tuffs and breccias, consisting of red and brown ash.
- b. Hard calcareous breccia, $4\frac{1}{2}$ ft. thick; in upper portion passes into an impure limestone; fossiliferous, with *Liothyrella boehmi* Thomson, &c.
- c. Thin-bedded bluish-grey clays and fine sandstones; tufaceous throughout; 17 ft. thick; thins out to the westward.
- d. Yellowish-brown polyzoan limestone, the upper band of Oamaru stone, 2 ft. to 4 ft. thick.
- e. Kakanui limestone, hard, semi-crystalline, crowded with fossils.

From bed *b*, which forms a projecting ledge on the sea-face, were collected the molluscs—

Aturia australis McCoy.
Emarginula wānnonensis Harris.
Solariella sulcatina Sut.
 ÷ *Astræa heliotropium* (Mart.).
 ÷ *Siphonium planatum* Sut.
Turritella semiconcava Sut. (= *mur-*
rayana of hand-list).
Capulus australis (Lamk.).
Ampullina suturalis (Hutt.).
Colubraria n. sp. (also loc. 642).
 Genus new to fauna.
Ficus transennus Sut.
Epitonium nympha (Hutt.). New
 for the Miocene.
Epitonium lyratum (Zitt.).
Fusinus n. sp.
Exilia sp. (?). Cast.
Siphonalia turrita Sut.
Scaphella elegantissima Sut.
Surcula fusiformis (Hutt.).
Pleurotomaria tertiaria McCoy.

Dentalium mantelli Zitt.
Dentalium solidum Hutt.
 ÷ *Glycymeris laticostata* (Q. & G.).
Mytilus huttoni Cossin. (= *striatus*
 of hand-list.)
Pecten aldingensis Tate.
Pecten polymorphoides Zitt.
Pecten huttoni (Park).
Venericardia acanthodes Sut.
Venericardia difficilis var. *benhami*
 (Thomson).
Cytherea chariessa Sut.
Cardium patulum (!) Hutt.
Cardium spatiosum (!) Hutt.
Cardium waitakiense Sut.
Cardium n. sp.
Protocardia sera Hutt.
Teredo hepaphyi Zitt.
Pholadomya neozelanica Hutt.
 Many casts, fragments, and im-
 pressions.

In addition to these, Uttley collected—

÷ <i>Turbo marshalli</i> Thomson.	<i>Pecten delicatulus</i> Hutt.
÷ <i>Turritella carlottæ</i> Watson.	<i>Pecten triphooki</i> Zitt.
<i>Siphonalia conoidea</i> (Zitt.).	÷ <i>Lima angulata</i> Sow.
<i>Siphonalia costata</i> (Hutt.).	<i>Chione meridionalis</i> (Sow.).
<i>Lapparia</i> sp.	÷ <i>Chione mesodesma</i> (Q. & G.).

The brachiopods from the horizon of the Kakanui tuffs were,—

<i>Liothyrella boehmi</i> Thomson.	<i>Ætheia gaulteri</i> (Morris).
<i>Liothyrella oamarutica</i> (Boehm).	<i>Neothyris tapirina</i> (Hutt.).
<i>Terebratulina suessi</i> (Hutt.).	<i>Hemithyris</i> sp.

Among the corals were *Balanophyllia hectori* Ten.-Woods, *Sphenotrochus huttonianus* Ten.-Woods, and the beautiful form *Trochocyathus mantelli* M. Edw. & H.

From bed *d*, lying immediately below the limestone, were collected—

÷ <i>Siphonalia nodosa</i> (Mart.).	÷ <i>Anomia huttoni</i> (?) Suter.
<i>Cymbiola corrugata</i> (Hutt.).	<i>Cucullæa alta</i> Sow.
<i>Epitonium lyratum</i> (Zitt.).	<i>Lima paleata</i> Hutt.
<i>Teredo heaphyi</i> Zitt.	÷ <i>Venericardia difficilis</i> (Desh.).
<i>Ostrea angasi</i> (?) Sow.	

From this bed Uttley also records—

<i>Turbo marshalli</i> Thomson.	<i>Dentalium solidum</i> Hutt.
÷ <i>Turritella carlottæ</i> Watson.	

The brachiopods from this bed include—

<i>Liothyrella boehmi</i> Thomson.	<i>Ætheia gaulteri</i> Morris.
<i>Terebratulina suessi</i> (Hutt.).	<i>Neothyris tapirina</i> (Hutt.).

The large echinoderm *Pericosmus compressus* McCoy occurs both in bed *b* and bed *d*.

The brachiopods collected from the Kakanui limestone were,—

<i>Liothyrella oamarutica</i> (Boehm).	<i>Ætheia gaulteri</i> (Morris).
<i>Terebratulina suessi</i> (Hutt.).	<i>Neothyris tapirina</i> (Hutt.).

From this limestone Uttley collected the following forms not found by the author:—

<i>Liothyrella concentrica</i> (Hutt.) (?).	<i>Hemithyris sublævis</i> Thomson.
<i>Terebratella kakanuiensis</i> Hutt.	

The Kakanui limestone is about 20 ft. thick, and has been extensively quarried for burning into lime. In places it is crowded with brachiopods. In its upper portion it becomes glauconitic and sandy. Besides brachiopods it contains a few molluscs, which are as a rule difficult to extract. The molluscs recorded from it by Uttley are,—

<i>Aturia australis</i> McCoy.	<i>Venericardia</i> sp.
<i>Pecten aldingensis</i> Tate.	

A fine example of *Aturia australis* from the Kakanui limestone is in the Otago University Museum. The first remains of the giant penguin *Palæudyptes antarcticus* Huxley were found in the Kakanui limestone by W. B. D. Mantell* in 1849.

* G. A. Mantell, *Quart. Jour. Geol. Soc.*, Aug., 1850, vol. vi, p. 675; and Thomas Huxley, *Quart. Jour. Geol. Soc.*, 1859, vol. xv.

Below the Kakanui limestone there is in places a band of soft polyzoan limestone of variable thickness. It is usually tufaceous and friable, as may be seen between the old limestone-quarry at Kakanui and Trig. T. This friable polyzoan band represents the upper band of Oamaru stone. It is often crumbling and friable, and where tufaceous usually contains small brachiopods, among which *Terebratulina suessi* (Hutt.) is always conspicuous.

From a point a little south of Trig. T the Kakanui limestone and underlying upper band of tufaceous Oamaru stone dip towards the sea, and along the coast for half a mile form a low undercut rock-shelf fronting the sea. To the southward, opposite the old quarry the limestone is bent up at the edge so as to override the Kakanui breccia and tuffs that are strongly developed from here to the North Head. The turning-up or warping of the southern edge of the limestone exposes the rocks below it on the coast below the quarry.

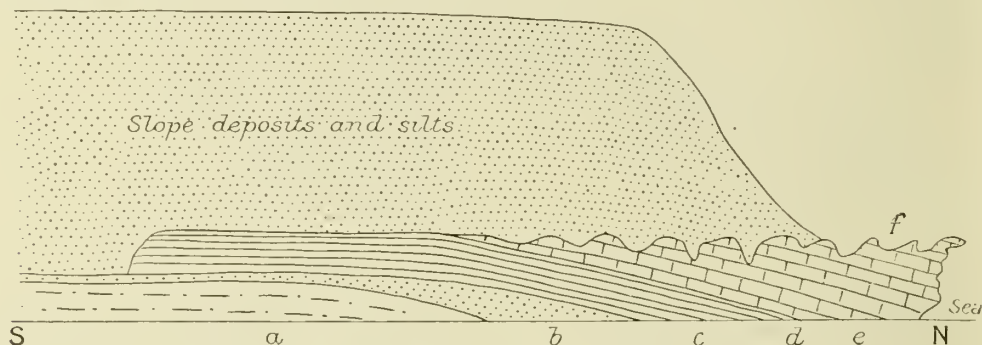


FIG. 30.—SECTION ON COAST NORTH OF KAKANUI QUARRY.

- a. Kakanui breccias and tuffs.
- b. Hard calcareous fossiliferous volcanic breccia; gradually loses its calcareous character to the southward, and merges into a mottled brownish-green tuff; 9 ft. thick.
- c. Thin-bedded blue and greyish-blue clays and fine soft sandstones. The upper 18 in. are fine tuffs; and all the material forming the clays and sandstones is tufaceous, and speckled throughout with pieces of ash and fine breccia. Thickness, 17 ft. From the clays was collected a single example of *Liothyrella boehmi* Thomson.
- d. Calcareous rubbly tufaceous bed, varying from 9 in. to 18 in. thick; richly fossiliferous. This is bed d of Fig. 29.
- e. Yellowish-grey polyzoan limestone; 36 ft. thick.
- f. Hard semi-crystalline limestone; 36 ft. thick.

The fossils collected from beds b and d have already been enumerated on the preceding page.

CONFIRMATORY SECTIONS.

Section from Beach below Trig. T to near Three Roads.

From a point on the beach near Three Roads southward for a mile the Kakanui tuffs occupy the whole of the coast-line, and in places attain a thickness of not less than 160 ft. At Three Roads, which is the most northerly point reached by them in this area, they strike almost north and south (magnetic), and dip east at an angle of 28° —that is, the strike is parallel with the shore-line. From this locality southward towards Kakanui the strike bends round with the trend of the coast, and at Two Roads, near Trig. T, it is N. 70° E. and the dip still seawards.

Along this portion of the coast the tuffs have been worn into a wide nearly level platform, which is seen at low water to be about 110 yards wide. On this plane of marine erosion the strike of the tuffs is conspicuously displayed by the long lines of projecting outcrop of the more resistant beds.

The sea-level plane of erosion is bounded on the landward side by low cliffs that are surmounted by the 12 ft. raised shelly beach which contours around the coast at the Rifle Butts and Cape Wanbrow.

At Two Roads the tuffs are calcareous, and brecciated with angular tachylitic material. Here they disappear below the limestone, which is followed by greensands.

Even where coarsely tachylitic, within a few feet of the limestone they contain numerous fossils, including molluscs, brachiopods, and corals. The material in which the fossils occur is so hard and coarsely brecciated with tachylitic fragments that the author in 1905 erroneously considered this rock a shattered basaltic flow. The few molluscs extracted from the calcareous matrix of this rock were,—

<i>Cymatium minimum</i> (?) (Hutt.).	÷ <i>Psammobia lineolata</i> Gray.
<i>Anomia</i> sp.	<i>Teredo heaphyi</i> Zitt.
<i>Chione meridionalis</i> (?) (Sow.).	

From the limestone as exposed in the road-cutting 150 yards due east of Trig. T, Uttley collected the brachiopods—

<i>Liothyrella oamarutica</i> (Boehm).	<i>Terebratella kakanuiensis</i> Hutt.
<i>Etheia gaulteri</i> (Morris).	<i>Hemithyris</i> sp., cf. <i>squamosa</i> (Hutt.).
<i>Terebratulina suessi</i> (Hutt.).	

From the overlying greensands the author collected *Pachymagas parki* (Hutt.), *Pecten huttoni* (Park), and *Pecten delicatulus* Hutt.

On the beach at Three Roads, at the northern limit reached by the Kakanui breccias and tuffs, the material in the upper portion is calcareous, finer in texture, and intensely tough. Here on the weathered surfaces of the rock were collected a few molluscs, including—

<i>Siphonalia turrita</i> Sut.	÷ <i>Dosinia cœrulea</i> (Reeve).
÷ <i>Diplodonta zelandica</i> (Gray).	<i>Panope worthingtoni</i> Hutt.

From this horizon of the tuffs Uttley collected—

<i>Lima</i> sp. aff. ÷ <i>angulata</i> Sow.	<i>Chione chilensis truncata</i> Sut.
<i>Ostrea</i> sp.	÷ <i>Mesodesma subtriangulatum</i> (Gray).
÷ <i>Venericardia purpurata</i> Desh.	

Section in Road-cutting, Deborah Road, Half a Mile due East of Rocky Peak.

The Kakanui limestone here lies directly on the Kakanui tuffs. It forms a shallow fold, as shown in Fig. 31.

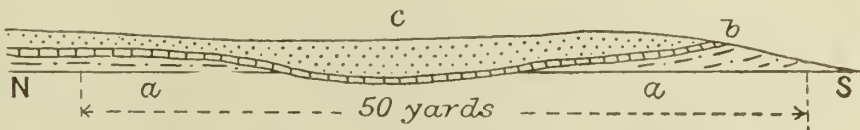


FIG. 31.—SECTION IN ROAD-CUTTING HALF A MILE DUE EAST OF ROCKY PEAK.

- a. Kakanui tuffs and breccias; 6 ft. showing at south end of cutting.
- b. Hard semi-crystalline limestone, from 2 ft. to 3 ft. thick showing in cutting.
- c. Surface elays, soil, and gravel.

The higher portion of bed a consists of coarse calcareous tuff containing augite, hornblende, olivine, and feldspar. The molluscs collected from this horizon were,—

÷ <i>Astræa heliotropium</i> (?) (Mart.).	<i>Pecten chathamensis</i> (?) Hutt
÷ <i>Siphonium planatum</i> Sut.	<i>Pecten huttoni</i> (Park).
÷ <i>Crepidula monoxyla</i> (?) (Less.) (= <i>crepidula</i> of hand-list).	<i>Pecten yahliensis</i> Ten.-Woods.
<i>Dentalium mantelli</i> (?) Zitt.	<i>Ostrea wuellerstorfi</i> Zitt.
<i>Glycymeris</i> sp.	÷ <i>Diplodonta zelandica</i> (Gray).
<i>Mytilus huttoni</i> Cossm. (= <i>striatus</i> of hand-list).	<i>Venericardia</i> sp.
<i>Pecten aldingensis</i> Tate.	<i>Cardium</i> sp.
	<i>Protocardia sera</i> (?) Hutt.

From the calcareous tuff or mineral breccia here Uttley collected the following species not found by the author:—

÷ *Turritella carlotta* Watson.

Siphonalia turrita Sut.

Emarginula wannonensis Harris.

Dentalium solidum Hutt.

Cardium sp.

÷ *Chione spissa* (Desh.).

÷ *Mesodesma subtriangulatum*
(Gray).

The brachiopods collected from the tuffs here were,—

Liothyrella oamarutica (Boehm).

Terebratulina suessi (Hutt.).

Ætheia gaulteri (Morris). Abundant.

Hemithyris depressa Thomson.

Magella carinata Thomson.

From this place have also been recorded—

Liothyrella boehmi Thomson.

Hemithyris sp., cf. *squamosa* (Hutton).

Liothyrella pulchra Thomson.

Besides molluscs and brachiopods, the author collected from the Kakanui breccia at this place teeth of *Carcharodon angustidens* Agassiz, *Lamna* and other fish, cetacean bones, plates of *Balanus*, *Cidaris* plates and spines, and numerous corals, including *Flabellum radians* Ten.-Woods and *Flabellum* sp.

From the limestone was collected *Liothyrella boehmi* Thomson.

In the road-cutting 330 yards south of last section 10 ft. of the tuffs and breccias are exposed, and 6 ft. of the limestone. The lowermost 9 in. of the limestone is here brecciated with basaltic fragments, and contains *Liothyrella boehmi* Thomson in abundance, also a large thick oyster (probably *Ostrea nelsoniana* Zitt.), and large fragments of cetacean bone.

About 120 yards from the Three Roads, in a shallow cutting in the road going west, there is an outcrop of grey calcareous glauconitic greensands, crowded with *Pachymagas parki* (Hutt.). Among the molluscs well enough preserved to be identified were collected *Pecten huttoni* (Park), *P. delicatulus* Hutt., *P. beethami* Hutt., and a *Natica*. *Cidaris* plates and spines, corals, and cup-shaped *Celepora* were also present in abundance.

The greensands at this place rest on tuffs which are highly calcareous in their upper portion.

Section in Road North of Rocky Peak.

In the road-cutting here are exposed 12 ft. of tuffs. Overlying the tuffs lies a thin bed of glauconitic basaltic conglomerate containing *Ostrea nelsoniana* Zitt., *Pecten delicatulus* Hutt., and *Liothyrella boehmi* Thomson. Above the conglomerate lies the hard semi-crystalline Flat Top Hill (Kakanui) limestone, which is tufaceous and friable in its lower portion. From the tufaceous horizon was collected *Liothyrella boehmi* Thomson.

Section at Teschemaker's old Quarry.

At Teschemaker's old Oamaru stone quarry, situated a mile east of Teschemaker's Railway-station, the Oamaru stone is interbedded with a bed of brown well-bedded tuffs 14 ft. thick. The lower 4 ft. of these tuffs is calcareous and mainly composed of comminuted shells, Polyzoa, corals, and echinoderm spines.

Among the molluscs collected from the tuffs were,—

÷ *Siphonium planatum* Sut.

Turritella sp. Cast.

Pecten delicatulus Hutt.

Pecten aldingensis Tate.

Pecten venosus Hutt.

Pecten huttoni (Park).

Teredo heaphyi Zitt.

Clavagella sp. Genus new to New Zealand fauna.

The only brachiopods collected here were a *Hemithyris* sp., a *Magella* sp., and *Ætheia gaulteri* (Morris).

Section at Totara old Stone-quarry.

In the old quarry near the railway-siding there are two bands of Oamaru stone, separated by a bed of fossiliferous calcareous tuff that is seen to vary from 18 in. to 6 ft. thick as exposed in the old tramway-cutting. From the tuffs were collected the brachiopods—

Ætheia gaulteri (Morris).

Magella carinata Thomson.

Terebratulina suessi (Hutt.).

The following molluscs were collected from the tuffs:—

† *Siphonium planatum* Sut.

Pecten delicatulus Hutt.

† *Anomia huttoni* (?) Sut.

Pecten yahliensis Ten.-Woods.

Section at Weston old Stone-quarry.

The section exposed in the face of this abandoned quarry shows two bands of Oamaru stone separated by a calcareous tuff.

Of the lower band of Oamaru stone there is exposed a thickness of 26 ft. The bed of calcareous tuff which follows varies from a few inches to 3 ft. thick. The upper band of Oamaru stone is 11 ft. thick, and contains peculiar lens-shaped pockets of tuff. In places the tuff-bed is crowded with brachiopods, among which were collected—

Neothyris uttleyi Thomson (MS.).

Liothyrella pulchra Thomson.

Neothyris tapirina (Hutt.).

Pachymagas parki (Hutt.).

From this band of tuff Uttley collected the brachiopods *Ætheia gaulteri* (Morris), and *Terebratulina suessi* (Hutt.).

Section at Trig. M, near Sebastopol.

The succession at this hill is quite clear, though the thickness of the beds cannot be determined in all cases, on account of slope deposit and tumbled blocks. The beds represented here are, in ascending order,—

(a.) Tuffs and breccias.

(b.) Tufaceous limestone, containing a bed of conglomerate 4 in. thick near the top, with pectens, &c., and brachiopods.

(c.) Tufaceous limestone, with irregular bands of hard semi-crystalline limestone, 6 ft. thick.

(d.) Bed of reddish-yellow tuffs, 5 ft. thick, with *Crepidula striata* (Hutt.).

(e.) Highly tufaceous limestone, 20 ft. thick, with numerous molluscs, brachiopods, and corals; containing splinters and broken crystals of hornblende and feldspar, as well as scattered well-rounded quartz pebbles.

The lower tuffs (beds a) are of considerable but unknown thickness. They are probably the Waiarekan tuffs.

Beds b, c, d, and e are undoubtedly Ototaran. The fauna of the uppermost bed (e) would tend to show that this horizon is the equivalent of the calcareous tuff band forming the closing member of the Kakanui tuffs, or perhaps of the Kakanui limestone itself. Collections from this bed were made by Thomson and Uttley in

1914. The result of these collections is given below. (T. & U.) = collected by Thomson and Uttley in 1914. (P.) = collected by Park in 1916.

<i>Emarginula wannonensis</i> Harris. (T. & U.).	÷ <i>Arca novæ-zealandiæ</i> Smith. (T. & U.)
<i>Trochus</i> n. sp. (T. & U.).	(= <i>decussata</i> of hand-list).
<i>Turbo</i> sp., operculum. (P.).	<i>Pecten aldingensis</i> Tate. (T. & U.). (P.).
<i>Serpulorbis siphio</i> (Lamk.) (?). (T. & U.).	<i>Pecten accrementus</i> Hutt. (T. & U.).
<i>Siphonium planatum</i> Sut. (T. & U.).	<i>Pecten delicatulus</i> Hutt. (P.).
<i>Turritella ambulacrum</i> Sow. (T. & U.).	<i>Pecten hutchinsoni</i> Hutt. (P.).
<i>Turritella symmetrica</i> Hutt. (T. & U.).	<i>Pecten venosus</i> Hutt. (T. & U.). (P.).
<i>Capulus australis</i> (Lamk.). (T. & U.).	÷ <i>Lima angulata</i> Sow. (T. & U.). (P.).
<i>Colyptræa maculata</i> (Q. & G.). (T. & U.).	÷ <i>Lima bullata</i> (Born). (T. & U.). (P.).
<i>Colyptræa maculata inflata</i> (Hutt.). (T. & U.).	<i>Lima huttoni</i> (?) Sut. (P.).
<i>Polinices amphialus</i> (Wats.). (T. & U.).	÷ <i>Chione spissa</i> (Desh.). (T. & U.)
<i>Polinices gibbosus</i> (Hutt.). (T. & U.).	(= <i>crassa</i> of hand-list).
<i>Polinices huttoni</i> (von Iher.). (T. & U.).	<i>Chione meridionalis</i> (Sow.). (P.).
<i>Ficus transennus</i> (?) Sut. (T. & U.).	<i>Cardium</i> sp. (T. & U.).
÷ <i>Gadinia conica</i> Angas. (T. & U.).	÷ <i>Protocardia pulchella</i> (Gray). (T. & U.).
<i>Dentalium solidum</i> Hutt. (T. & U.).	

Of the twenty-nine species of molluscs enumerated above no less than thirteen (or 45 per cent.) are Recent. It is probable that a more exhaustive collection would reduce the proportion of living forms.

The brachiopods collected from this bed by Thomson and Uttley were,—

<i>Liothyrella oamarutica</i> (Boehm).	<i>Terebratulina suessi</i> (Hutt.).
<i>Liothyrella boehmi</i> Thomson.	<i>Ætheia gaulteri</i> (Morris).
<i>Liothyrella pulchra</i> Thomson.	<i>Hemithyris</i> sp., cf. <i>squamosa</i> (Hutt.).
<i>Terebratella totaraensis</i> Thomson.	

Section on North Bank of Parson's Creek.

Near the mouth of this stream, and at intervals along the north bank, there are outcrops of tufts capped by a bed of basaltic conglomerate 8 ft. thick that in its turn is followed by a bed of yellowish-brown tufaceous calcareous sandstone or impure coralline limestone. 20 ft. thick. The conglomerate is calcareous, and in places glauconitic, and from it were collected—

<i>Dentalium mantelli</i> Zitt.	<i>Ostrea nelsoniana</i> Zitt. (?)
<i>Ostrea mackayi</i> Sut.	<i>Ostrea wuellerstorfi</i> Zitt.

The limestone is capped by a basalt-flow, and the tufts below the conglomerate are underlain by basalts. The succession of rocks is much like that on the north bank of Awamoa Creek near Deborah. Though these rocks are isolated from all well-defined horizons, their fossil-contents would place them in the Ototaran.

Section in Road-cutting near Ardgowan Bridge across Oamaru Creek.

About 65 yards from the bridge across Oamaru Creek, on the east side of the road leading to Ardgowan Creamery, there is an outcrop of Oamaru stone which is followed conformably by a tufaceous crumbling polyzoan bed about 18 in. thick. Above this lies a bed of basaltic conglomerate 6 ft. thick, with a calcareous glauconitic matrix.

The Oamaru stone is the typical building-stone. The thin bed of friable polyzoan material contains, besides Polyzoa and echinoderm remains, the fragments of molluscs

(none of which could be extracted in good condition), and some brachiopods, the latter including—

Ætheia gaulteri (Morris).

Terebratulina sp. (?), probably *suessi* (Hutt.).

Terebratella sp., perhaps *neozelandica* von Iher. (new to Oamaru district).

The basaltic conglomerate here seems to occupy the same stratigraphical position as the basaltic conglomerate at Hutchinson's Quarry. From it were collected *Ætheia gaulteri* (Morris), a large *Terebratula* resembling *Liothyrella boehmi* Thomson, and some well-preserved teeth of *Carcharodon angustidens* Agassiz.

The conglomerate also contains many molluscs, most fragmentary and difficult to identify. A list of those collected here is given in the chapter dealing with the Hutchinsonian.

Section at Fortification Hill.

Here the Oamaru stone is intercalated with several beds of yellowish-coloured tufaceous polyzoan material. The main body of Oamaru stone rests on the Waiarekan tuffs, which are well exposed at the foot of the limestone escarpment.

In the lowermost of the tufaceous beds immediately overlying the main body of Oamaru stone, at a point opposite the village of Alma, were collected several brachiopods, among which were, —

Liothyrella pulchra Thomson.

Terebratulina suessi (Hutt.).

Terebratella totaraensis Thomson.

Hemithyris sp.

(See also bottom of page 55.)

VOLCANIC ROCKS OVERLYING THE OTOTARAN.

From Boatman's Harbour to the end of the inner breakwater at Oamaru, and from there westward to near the Waiareka Junction, the high ground is occupied by a massive development of tachylitic breccia, generally much jointed and decomposed. A fine exposure of this breccia is seen in the sea-cliffs between the outer breakwater and Boatman's Harbour, and at the old Harbour Board quarry at the end of the outer breakwater, where the quarry-face is over 100 ft. high at its highest point.

The tachylitic breccia consists of large and small angular blocks, and fragments of tachylite set in a calcareous matrix. At the old quarry and in the cliffs below the lighthouse the breccia is traversed by many nearly vertical veins of sedimentary material.

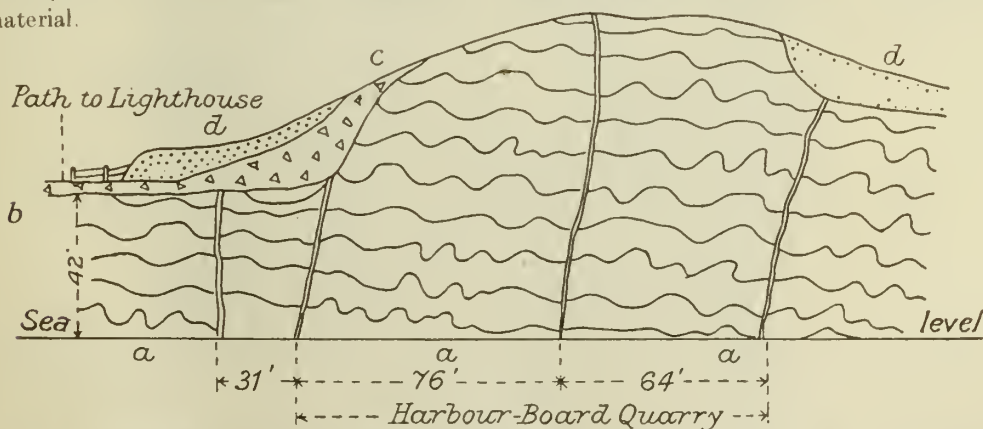


FIG. 32.—SECTION FROM STEPS LEADING UP TO LIGHTHOUSE TO HARBOUR BOARD QUARRY AT END OF OUTER BREAKWATER.

a. Tachylitic breccia,

b. Raised beach, with Recent shells (under slope deposit),

c. Slope deposit.

d. Pleistocene silts.

The tachylitic breccia is probably a submarine basaltic flow that cooled rapidly and became shattered by coming in contact with the sea-water. The calcareous matrix consists of impure limestone consolidated by secondary calcite.

The sedimentary veins which traverse the tachylitic breccia consist of glauconitic sandstone and impure limestone, the latter mainly composed of comminuted Polyzoa and echinoderm remains. As a rule, these veins vary from almost nothing to 6 in. wide, though some are wider and irregular in form. The limestone vein at the bottom of the steps leading up to the lighthouse varies from 12 in. to 18 in. wide. Its walls are slickensided and scored with nearly vertical grooves and striae. It is apparent that rock-movement took place after the filling of the veins. Fig. 32A is an enlargement of the vein at the steps.

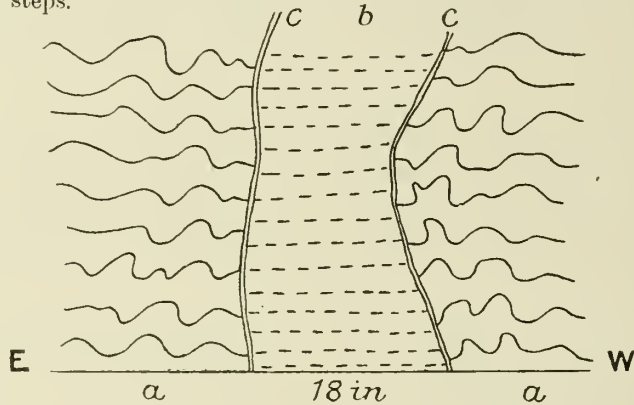


FIG. 32A.—ENLARGED SECTION OF LIMESTONE VEIN IN TACHYLITIC BRECCIA AT STEPS LEADING UP TO OAMARU LIGHTHOUSE.

a. Tachylitic breccia.

b. Impure sandy glauconitic limestone.

c. Thin sheets of fine-grained limestone varying from 0 to 1½ in. thick, apparently secondary calcite.

As shown in Plate II and Fig. 4, the tachylitic breccia overlies the Boatman's Harbour beds at South Oamaru. It is followed by a great thickness of well-bedded tuffs and breccias, which are well exposed on the golf-links, in the railway-cuttings going up to Waiareka Junction, and in the old Oamaru Borough quarry in Chamberlin Street, opposite the Oamaru Gardens.

At the old road-metal quarry at the Chamberlin Street end of Oamaru Creek Gorge, and at the present Oamaru Borough road-metal quarry in the gorge, the tuffs and breccias are overlain by a dolerite, which continues from the upper end of the gorge to the old Phoenix dam.

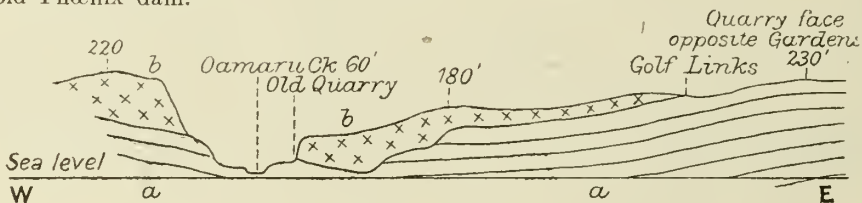
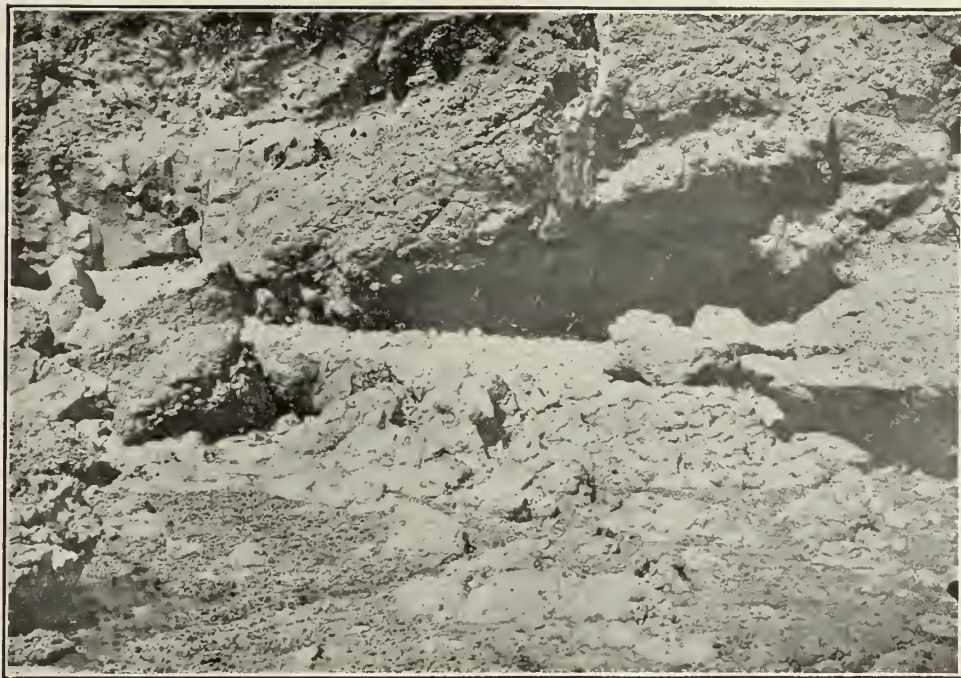


FIG. 33.—SECTION ALONG CHAMBERLIN STREET, OPPOSITE OAMARU GARDENS.

a. Tuffs and breccias.

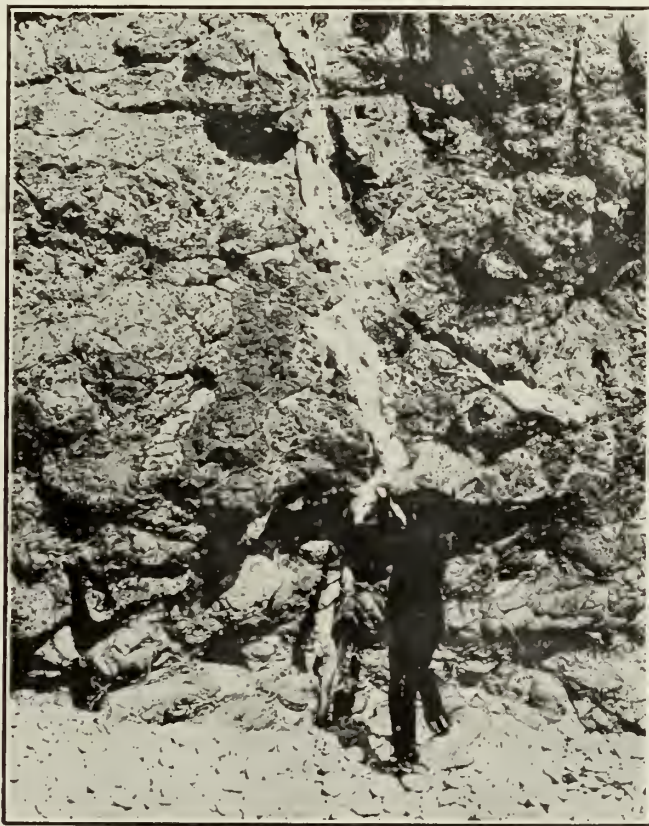
b. Dolerite.

The dolerite consists of plagioclase and augite in well-developed intergrown crystals. At the upper end of the old Phoenix dam, a mile above the junction of Parson's Creek, the tuffs and a flow of basalt are underlain by an outcrop of hard grey semi-crystalline flaggy limestone. There is nothing to indicate the age of this limestone, but as judged by its relationship to the tuffs it may be referred to the Ototaran.



James Park, photo.]

A. FOSSILIFEROUS LIMESTONE VEIN IN TACHYLITIC BRECCIA, NEAR BREAKWATER, OAMARU.



A. C. Gifford, photo.]

B. FOSSILIFEROUS LIMESTONE VEIN IN TACHYLITIC BRECCIA, NEAR BREAKWATER, OAMARU.

CHAPTER VII.

HUTCHINSONIAN STAGE.

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(a) Glauconitic sandstone. (b) Glauconitic greensands. (c) Conglomerate, mainly basaltic.

CONGLOMERATE.

THE Hutchinsonian consists of two well-marked members—namely, glauconitic sands (the Lower Hutchinsonian) and a glauconitic calcareous sandstone (the Upper Hutchinsonian = Waitaki stone). The basal conglomerate is present only in the Oamaru area. The stratigraphical unconformity between the Kakanui limestone and the greensands as seen at Kakanui, All Day Bay, and Deborah is only local, and has no palæontological significance. Elsewhere complete conformity exists between the Ototaran and Hutchinsonian.

The greensands at All Day Bay and Kakanui rest directly on a corroded and uneven surface of the hard semi-crystalline Kakanui limestone; but at Deborah, Hutchinson's Quarry, Devil's Bridge, and Landon Creek a bed of conglomerate lies between the limestone and the greensands.

At the Devil's Bridge the conglomerate consists of rounded and semi-rounded pebbles of hard siliceous cement-stone set in a glauconitic sandy matrix; but elsewhere the conglomerate is basaltic, the matrix consisting of fine volcanic ash often mixed with glauconitic sands. Almost everywhere the pebbles are coated with a thin shining dark-brown or black film that is mainly tricalcic phosphate.

The presence of the conglomerate is an evidence that some portion of the fragmental volcanic material ejected during the Ototaran, or an earlier stage, had been uplifted by a local crustal movement, or, what is perhaps more probable, piled up till it formed shallow reefs, which thereby became subject to the wear-and-tear of the tides and prevailing sea-currents. The glauconitic material contained in the matrix would lead to the inference that the conglomerate was not formed as an ordinary fluvio-marine gravel. This view is further strengthened by the fact that the conglomerate is followed conformably by glauconitic greensands that contain corals, bryozoans, echinoderms, pectens, and brachiopods—the fauna of off-shore banks within the 20-fathom line covered with clear water, and not that of a turbid sea-strand.

Fauna of Conglomerate.

At Hutchinson's Quarry the conglomerate contains fossils, but none that could be identified were extracted from it. The molluscs collected from the conglomerate near Ardgowan Creamery were,—

<i>Clio</i> sp.	<i>Melina zealandica</i> (?) Sut.
÷ <i>Capulus australis</i> (?) (Lamk.).	<i>Pecten delicatulus</i> Hutt.
<i>Ampullina suturalis</i> (?) (Hutt.).	<i>Lima colorata</i> (?) Hutt.
<i>Cypræa treliassickensis</i> (?) Sut.	<i>Lima huttoni</i> (?) Sut.
<i>Galeodea senex</i> (Hutt.).	<i>Ostrea nelsoniana</i> Zitt.
<i>Nucula sagittata</i> Sut.	<i>Protocardia sera</i> Hutt.
÷ <i>Anomia walteri</i> (?) Hect.	<i>Panope worthingtoni</i> Hutt.

From this conglomerate were also collected teeth of *Carcharodon angustidens* Agassiz, and the brachiopods *Ætheia gaulteri* (Morris) and *Liothyrella boehmi* (?) Thomson.

GLAUCONITIC GREENSANDS (LOWER HUTCHINSONIAN).

The glauconitic sandy beds at All Day Bay, Kakanui, Hutchinson's Quarry, and Grant's Creek are loose and incoherent, but at the upper end of Target Gully, at Landon Creek, and in the Waitaki area they form fairly compact glauconitic sandstones.

Fauna of Glauconitic Greensands.

The fauna of this horizon is distinguished by the abundance of the brachiopod *Pachynagas parki* (Hutt.), by the presence of the corals *Isis dactyla* Ten.-Woods, and *Mopsea hamiltoni* (Thomson), and of the cup-shaped bryozoan *Celleporaria nummularia* Busk. Besides these there occur many pectens and other molluscs. *Pachynagas parki* is present almost everywhere, but the other fossils mentioned may be abundant at one place and absent at another.

The molluscs collected from the greensands at Deborah and Hutchinson's Quarry were,—

	Deborah.	Hutchinson's Quarry.
<i>Epitonium</i> n. sp.	X	..
— <i>lyratum</i> (Zitt.)	..	X
<i>Xenophora corrugata</i> (Reeve)	X	..
<i>Turritella concava</i> (?) Hutt.	X	..
÷ <i>Siphonalia dilatata</i> (Q. & G.)	X	..
<i>Teredo hepaphyi</i> Zitt.	X	..
<i>Struthiolaria tuberculata</i> Hutt.	X	..
<i>Dentalium solidum</i> Hutt.	X	..
<i>Cymbiola corrugata</i> (Hutt.)	X	..
<i>Fusinus solidus</i> (?) Sut.	X	..
<i>Cardium patulum</i> (?) Hutt.	X	..
— <i>spatiosum</i> (?) Hutt.	X	..
<i>Lima colorata</i> Hutt.	X	X
— <i>paleata</i> Hutt.	X	X
<i>Mactra attenuata</i> Hutt.	X	..
<i>Panope worthingtoni</i> Hutt.	X	..
— <i>orbata</i> Hutt.	..	X
<i>Cucullæa alba</i> Sow.	..	X
÷ <i>Diplodonta globularis</i> (Lamk.)	..	X
<i>Ostrea wuellerstorfi</i> Zitt.	..	X
<i>Paphia curta</i> Hutt.	..	X
<i>Pecten beethami</i> Hutt.	X	X
— <i>hutchinsoni</i> Hutt.	X	X
— <i>huttoni</i> (Park)	X	X
— <i>semiplicatus</i> Hutt.	X	X
— <i>yahliensis</i> Ten.-Woods	..	X
÷ — <i>radiatus</i> Hutt.	..	X
÷ <i>Protocardia pulchella</i> (Gray)	..	X
— <i>sera</i> Hutt.	X	X
÷ <i>Siphonium planatum</i> Sut.	..	X
÷ <i>Venericardia purpurata</i> (Desh.)	..	X

Of the thirty-one molluscs enumerated above, six (or 19.3 per cent.) are Recent.

GLAUCONITIC SANDSTONE (UPPER HUTCHINSONIAN).

The glauconitic sandstone follows the greensands conformably at the shell-bed (Target Gully), at the shell-bed (Ardgowan), at the Devil's Bridge, at Landon Creek (west branch and main branch), and Big Flume Creek, Waitaki Valley. At the shell-bed, Target Gully, it consists of soft glauconitic sandstone interbedded with hard yellowish-brown sandstone bands. At the Devil's Bridge it forms the natural bridge and the cliffs bounding the stream below that place. At Landon Creek it is a compact yellowish-brown calcareous glauconitic sandstone, and at Big Flume Creek a yellowish-brown calcareous glauconitic sandstone interbedded with thin, more calcareous, bands that weather out in the cliff-faces as projecting cornices. Here it is indistinguishable from the typical Waitaki stone, which forms long horizontal escarpments at many places on the south side of the Waitaki Valley between Barton's and Otekaieke.

Target Gully Sections.

The olive-green well-bedded calcareous tuffs which underlie the Hutchinson Quarry limestone near Eden Street, Oamaru, crop out on the same slope 250 yards farther up Target Gully, at a height of 110 ft. above the sea—that is, the beds have risen 43 ft. in that distance. At this point there is no outcrop of the fossiliferous Hutchinsonian beds, but small fragments of hard grey semi-crystalline limestone occur in a few places on the grassy slope above the tuff-outcrops. Some 40 yards farther up the gully, still on the east slope, the yellowish-brown calcareous glauconitic sandstone crops out at 150 ft. above the sea. It is in places crowded with casts, many of which are those of *Pachymagas parki* (Hutton).

Still higher up the gully the glauconitic sandstone again crops out at the 180 ft. contour, at a point about half-way between Hutchinson's Quarry and the Town Belt. South of the Town Belt boundary it forms a continuous outcrop 45 yards long. Here the underlying softer glauconitic rock has been worn away, leaving the harder glauconitic sandstone band as a projecting ledge in the form of a low rock shelter.

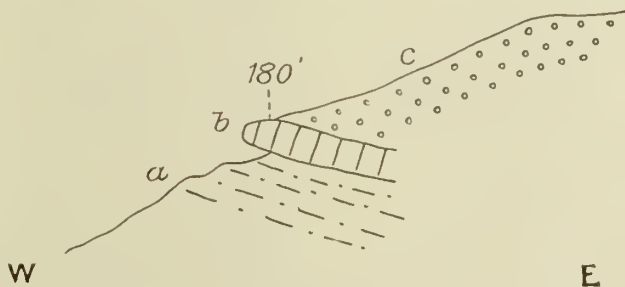


FIG. 34.—SECTION 20 YARDS SOUTH OF TOWN BELT, NEAR TARGET GULLY SHELL-BED.

a. Soft glauconitic sandstone. b. Band of hard glauconitic sandstone, 2 ft. to 4 ft. exposed
c. Pleistocene high-level greywacke gravels, 60 ft. thick.

From Hutchinson's Quarry to the Town Belt the Hutchinsonian beds are overlain by a thick deposit of high-level greywacke gravel. At the Town Belt the hard band of glauconitic sandstone, which has been described above as cropping out at intervals on the grassy slope, has been worn away; and in the shallow gutter thus formed there occurs what has been described as the Target Gully shell-bed of Awamoan age (Fig. 35).

At the Town Belt the Target Gully shell-bed lies on a soft glauconitic sandstone. About 20 ft. below the shell-bed this sandstone becomes strongly glauconitic and

calcareous. As exposed in the road-cutting it is friable, jointed, and seamed with soft powdery carbonate of lime. The section from Target Creek eastward along the Town Belt is shown in Fig. 35.

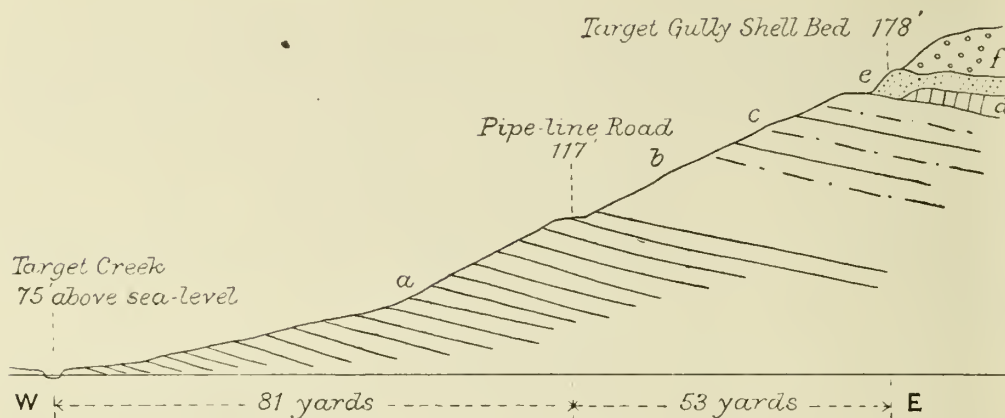


FIG. 35.—SECTION AT TARGET GULLY SHELL-BED.

- a. Well-bedded olive-green tufts.
 b. Unknown, obscured by slope deposit.
 c. Soft glauconitic sandstone, fossiliferous.
 d. Band of hard yellowish-brown glauconitic sandstone, 2 ft. to 4 ft. thick.
 e. Target Gully shell-bed (Awamoan), 6 ft. exposed.
 f. Surface clays and gravels.

The molluscs found in the glauconitic sandy bed below the shell-bed at Target Gully were,—

- | | |
|--|---|
| <i>Acteon præcursorius</i> Sut. | <i>Mytilus huttoni</i> Cossm. (= <i>striatus</i> of hand-list). |
| <i>Alectrion socialis</i> (Hutt.). | ÷ <i>Natica zelandica</i> Q. & G. |
| <i>Ancilla papillata</i> (Tate). | * <i>Nucula sagittata</i> Sut. |
| ÷ <i>Anomia huttoni</i> Sut. | ÷ <i>Ostrea corrugata</i> Hutt. |
| ÷ <i>Arca novæ-zealandiæ</i> Smith. | <i>Panope orbita</i> Hutt. |
| <i>Arca subvelata</i> Sut. | <i>Pecten hutchinsoni</i> Hutt. |
| ÷ <i>Calliostoma pellucidum</i> (Val.). | <i>Pecten huttoni</i> (Park). |
| <i>Calyptrea maccoyi</i> Sut. | ÷ <i>Pecten radiatus</i> Hutt. |
| ÷ <i>Calyptrea maculata</i> (Q. & G.). | <i>Pecten semiplicatus</i> (?) Hutt. (fragment only). |
| ÷ <i>Cantharidus tenebrosus</i> A. Ad. | <i>Pecten williamsoni</i> Zitt. |
| <i>Chione meridionalis</i> (Sow.). | <i>Pecten yahliensis</i> Ten.-Woods. |
| <i>Corbula humerosa</i> Hutt. | <i>Placunanomia incisura</i> Hutt. |
| <i>Corbula pumila</i> Hutt. | ÷ <i>Placunanomia zelandica</i> (Gray). |
| ÷ <i>Crassatellites obesus</i> (A. Ad.). | <i>Polinices gibbosus</i> (Hutt.). |
| ÷ <i>Crepidula monoxyla</i> (Less.). | ÷ <i>Psammobia lineolata</i> Gray. |
| <i>Crepidula gregaria</i> Sow. | ÷ <i>Siphonalia caudata</i> (?) (Q. & G.). |
| <i>Cucullæa alta</i> Sow. | <i>Siphonalia nodosa</i> Zitteli Sut. |
| <i>Cylichnella soror</i> Sut. | <i>Siphonalia</i> sp., cf. <i>subnodosa</i> (in bad condition). |
| <i>Dentalium mantelli</i> Zitt. | ÷ <i>Siphonium planatum</i> Sut. |
| <i>Dentalium solidum</i> Hutt. | <i>Struthiolaria cincta</i> Hutt. |
| ÷ <i>Diplodonta globularis</i> (Lamk.). | <i>Submarginula elata</i> Sut. |
| ÷ <i>Diplodonta zelandica</i> (Gray). | <i>Surcula fusiformis</i> (Hutt.). |
| <i>Drillia callimorpha</i> Sut. | |
| <i>Cymbiola corrugata</i> (Hutt.). | |
| <i>Latirus acuticingulatus</i> Sut. | |

* Marshall's *N. hartvigiana* is no doubt this.

- | | |
|---|---|
| ÷ <i>Lima bullata</i> (Born). | ÷ <i>Tellina glabrella</i> Desh. |
| <i>Lima colorata</i> Hutt. | <i>Terebra oryeta</i> Sut. |
| ÷ <i>Limopsis aurita</i> (Brocchi). | <i>Teredo heaphyi</i> Zitt. |
| <i>Limopsis zitteli</i> von Iher. | ÷ <i>Turbonilla zealandica</i> (Hutt.). |
| ÷ <i>Loripes concinna</i> Hutt. | <i>Turritella concava</i> Hutt. |
| <i>Loripes laminata</i> Hutt. | <i>Turritella semiconcava</i> Sut. |
| <i>Macrocallista assimilis</i> (Hutt.). | (= <i>murrayana</i> of hand-list). |
| ÷ <i>Macrocallista multistriata</i> (Sow.). | ÷ <i>Venericardia purpurata</i> (Desh.). |
| ÷ <i>Malletia australis</i> (Q. & G.). | ÷ <i>Venericardia difficilis</i> (Desh.). |
| <i>Mangilia canaliculata</i> Sut. | <i>Venericardia pseutes</i> Sut. |
| <i>Mangilia tenuilirata</i> (?) Sut. | ÷ <i>Venericardia lutea</i> (Hutt.) (= <i>ze-</i> |
| <i>Marginella harrisi</i> Cossm. | <i>landica</i> of hand-list). |
| ÷ <i>Modiolus australis</i> (Gray). | ÷ <i>Siliquaria weldii</i> Ten.-Woods (new |
| ÷ <i>Monodonta coracina</i> (Trosch.). | as fossil). |

Of the seventy-two species enumerated above, twenty-nine (or 40.3 per cent.) are still living. It is not a little curious that some living forms are present in these glauconitic beds that have not been found in the overlying Awamoan shell-bed.

The brachiopods found in this bed (c) were *Hemithyris nigricans* (Sow.), *Pachymagas parki* (Hutt.), and *Pachymagas trevisickensis* Thomson.

From the glauconitic sandy beds lying immediately below the Ardgowan shell-bed were collected—

- | | |
|--|---|
| <i>Turritella semiconcava</i> Sut. | ÷ <i>Lima suteri</i> Dall. |
| (= <i>murrayana</i> of hand-list). | ÷ <i>Crassatellites obesus</i> (A. Ad.). |
| <i>Calyptraea alta</i> (Hutt.). | ÷ <i>Venericardia lutea</i> (Hutt.) (= <i>ze-</i> |
| ÷ <i>Malletia australis</i> (Q. & G.). | <i>landica</i> of hand-list). |
| <i>Limopsis catenata</i> Sut. | <i>Venericardia pseutes</i> Sut. |
| ÷ <i>Modiolus australis</i> (Gray). | ÷ <i>Zenatia acinaces</i> (Q. & G.). |
| <i>Pecten huttoni</i> (Park). | <i>Cytherea chariessa</i> Sut. |

The Ardgowan shell-bed crops out on the terrace-face on the east side of Oamaru Creek, about three-quarters of a mile past the Ardgowan Creamery. It can be seen from the Devil's Bridge Road.

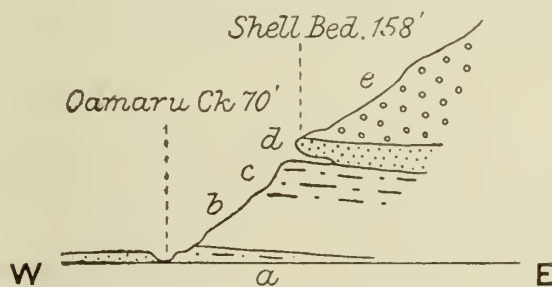


FIG. 36.—SECTION AT ARDGOWAN SHELL-BED.

- | | |
|---|------------------------------------|
| a. Soft dark-green glauconitic sands, 4 ft. showing. | d. Shell-bed (Awamoan). |
| b. Unknown. | e. High-level Pleistocene gravels. |
| c. Soft brown sandstone, in places slightly glauconitic; fossiliferous. | |

The fossil molluscs enumerated above were collected from a point a few yards north of the rock shelter formed by the overhanging shell-bed, and 6 ft. below the bottom of that bed.

The molluscs collected from the glauconitic sandstone at Devil's Bridge (bed *d*, Fig. 24) have already been recorded (page 62) in Chapter VI, but are recapitulated here for purposes of reference, as follows:—

- | | |
|---|--|
| ÷ <i>Ampullina undulata</i> (?) Hutt. | <i>Pecten beethami</i> Hutt. |
| <i>Astarte australis</i> Hutt. | <i>Pecten huttoni</i> (Park). |
| ÷ <i>Calyptræa maculata</i> (Q. & G.). | <i>Pecten yahliensis</i> Ten.-Woods. |
| <i>Chione meridionalis</i> (Sow.). | <i>Teredo heaphyi</i> Zitt. |
| ÷ <i>Crassatellites obesus</i> (A. Ad.). | <i>Turritella concava</i> Hutt. (two fragments). |
| <i>Cucullæa alta</i> (?) Sow. (fragment). | <i>Turritella semiconcava</i> Sut. |
| <i>Emarginula wammonensis</i> Harris. | ÷ <i>Venericardia purpurata</i> (Desh.). |
| <i>Lima colorata</i> Hutt. | <i>Venericardia pseutes</i> Sut. |
| <i>Lima paleata</i> Hutt. | |

Upper Target Gully Sections.

The Hutchinson Quarry beds crop out at many places on the pipe-line track on the east side of Target Gully, and at several places on the opposite side of the gully. The section at a point three-quarters of a mile above the Town Belt, and on the same side as the Target Gully shell-bed, is shown in Fig. 37.

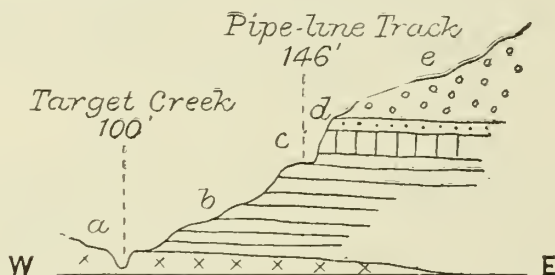


FIG. 37.—SECTION ON EAST SIDE OF TARGET GULLY, THREE-QUARTERS OF A MILE ABOVE TOWN BELT.

- | | |
|--|---|
| a. Basalt. | d. Rusty-brown glauconitic sandstone; 9 ft. exposed; contains <i>Pachymagas parki</i> (Hutt.), <i>Pecten huttoni</i> (Park), and <i>Pecten beethami</i> Hutt. |
| b. Olive-green tuffs, with thin lenses of hard limestone in upper portion. | e. High-level gravels. |
| c. Hard semi-crystalline limestone, 10 ft. to 17 ft. thick. | |

The basaltic conglomerate which is present between the limestone and greensands at Hutchinson's Quarry is absent in the upper end of Target Gully. The section exposed in Target Gully a mile above the Town Belt is shown in Fig. 38.

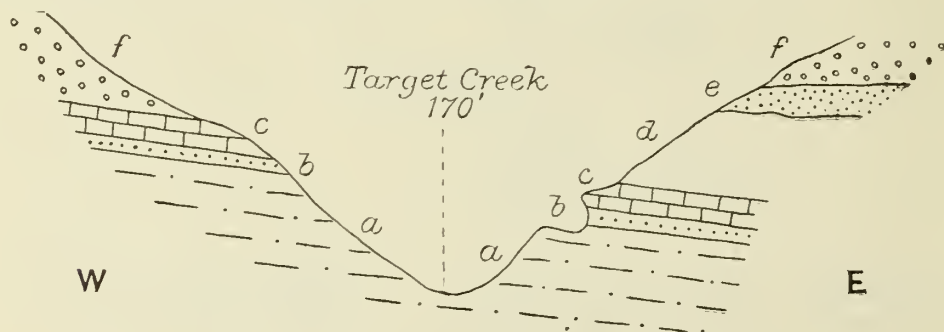


FIG. 38.—SECTION ACROSS TARGET GULLY ONE MILE ABOVE TOWN BELT.

- | | |
|---|---|
| a. Olive-green tuffs with limestone bands. | b. Impure tufaceous limestone, 2 ft. to 4 ft. |
| c. Glauconitic sandstone, 8 ft. exposed; where oxidized, soft and friable; forms a continuous outcrop 90 yards long; fossiliferous; crowded with <i>Pachymagas parki</i> (Hutt.). | d. Unknown. |
| | e. Fine beach sand. |
| | f. High-level gravel. |

Section a Mile and a Half South of Duntroon.

From Duntroon southward the Waitaki stone forms a steep escarpment that extends nearly to Barton's, a distance of over two miles. The section exposed in the cliff-face two miles from Duntroon is shown in Fig. 39.

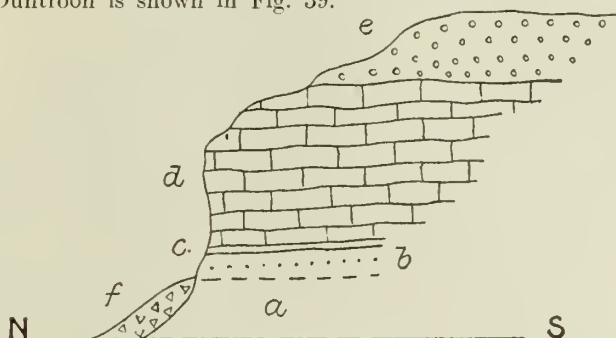


FIG. 39.—SECTION TWO MILES SOUTH OF DUNTROON.

- | | |
|---|---|
| <p>a. Unknown; covered by talus.</p> <p>b. Soft greyish-blue glauconitic sandstone; does not contain fossils where examined, except fucoid stems; thickness exposed, 18 ft.</p> <p>c. Dark-green glauconitic sandstone, which becomes friable on exposure to the weather; thickness, 3 ft., crowded with fossils, mostly brachiopods, molluscs, and corals (Lower Hutchinsonian).</p> | <p>d. Glauconitic sandstone interbedded with numerous thin nodular layers of harder more calcareous sandstone that approach an impure limestone. The higher portion is yellowish-brown, and consists of softer material with fewer calcareous layers; thickness, 64 ft. showing (Upper Hutchinsonian).</p> <p>e. High-level Pleistocene gravels.</p> <p>f. Talus.</p> |
|---|---|

Among the molluscs collected from the soft glauconitic sandstone (bed c) were,—

- | | |
|---|-------------------------------------|
| <i>Pecten huttoni</i> (Park) (very abundant). | <i>Lima paleata</i> Hutt. |
| <i>Pecten beethami</i> Hutt. | <i>Lima levigata</i> Hutt. |
| | ÷ <i>Limopsis aurita</i> (Brocchi). |

Brachiopods are very numerous in this bed, and the following species were collected :—

- | | |
|---------------------------------------|---|
| <i>Pachymagas ellipticus</i> Thomson. | <i>Neothyris</i> sp. |
| <i>Pachymagas huttoni</i> Thomson. | <i>Neothyris tapirina</i> (Hutt.). |
| <i>Ætheia gaulteri</i> (Morris). | <i>Terebratulina suessi</i> (Hutt.). |
| <i>Rhizothyris rhizoida</i> (Hutt.). | <i>Liothyrella landonensis</i> Thomson. |

At the base of the Waitaki stone (bed d) there occur many fine examples of the echinoderm *Pericormus compressus* McCoy.

Section at Otiake, Five Miles below Kurow.

At this place the Waitaki stone is more arenaceous, and hence softer, than at most places; and here Marshall and Uttley made a considerable collection of molluscs from it in 1914,* from a face some 50 ft. in height. The species they collected were,—

- | | |
|--|--|
| <i>Turritella cavershamensis</i> Harris. | <i>Terebra orycta</i> Sut. |
| <i>Turritella semiconcava</i> Sut. | <i>Surcula</i> n. sp. |
| ÷ <i>Struthiolaria vermis</i> (Mart.). | <i>Surcula</i> n. sp. |
| <i>Crepidula gregaria</i> Sow. | <i>Drillia callimorpha</i> Sut. |
| <i>Crepidula striata</i> (Hutt.). | <i>Bathytoma sulcata excavata</i> Sut. |
| ÷ <i>Calyptrea maculata</i> (Q. & G.). | <i>Euthria</i> sp. |
| ÷ <i>Natica zelandica</i> Q. & G. | <i>Borsonia rudis</i> (Hutt.) |

* *Trans. N.Z. Inst.*, vol. xlvii, 1915, p. 383. Mr. Uttley states (*vide* Dr. J. A. Thomson) that the beds from which the collection were made lie above the Waitaki stone, and are undoubtedly Awamoan.

<i>Polinices huttoni</i> von Iher.	<i>Mangilia tenuilirata</i> Sut.
<i>Polinices gibbosus</i> (Hutt.).	<i>Mangilia</i> n. sp.
<i>Ampullina suturalis</i> (Hutt.).	<i>Dentalium solidum</i> Hutt.
<i>Sinum (Eunaticina) cinctum</i> (Hutt.)	<i>Dentalium mantelli</i> Zitt.
(<i>Polinices</i> of hand-list).	<i>Cucullaea attenuata</i> Hutt.
÷ <i>Trichotropis clathrata</i> Sow.	÷ <i>Limopsis aurita</i> (Brocchi).
<i>Epitonium lyratum</i> (Zitt.).	÷ <i>Modiolus australis</i> (Gray).
<i>Fusinus</i> sp.	÷ <i>Pecten zelandiae</i> Gray.
<i>Mitra</i> n. sp.	<i>Pecten huttoni</i> (Park).
<i>Siphonalia conoidea</i> (Zitt.).	<i>Lima colorata</i> Hutt.
÷ <i>Siphonalia nodosa</i> (Mart.).	÷ <i>Crassatellites obesus</i> (A. Ad.).
<i>Cominella pulchra</i> Sut.	÷ <i>Venericardia difficilis</i> (Desh.).
÷ <i>Murex zelandicus</i> Q. & G.	÷ <i>Divaricella cumingi</i> (Ad. & Ang.).
<i>Typhis maccoyi</i> Ten.-Woods.	÷ <i>Zenatia acinaces</i> (Q. & G.).
÷ <i>Fulgoraria gracilis</i> (Swains.).	÷ <i>Dosinia greyi</i> Zitt.
<i>Cymbiola corrugata</i> (Hutt.).	÷ <i>Cytherea oblonga</i> (Hanley).
<i>Ancilla hebera</i> (Hutt.).	<i>Cytherea</i> n. sp.
÷ <i>Ancilla novæ-zelandiæ</i> (Sow.).	÷ <i>Macrocallista multistriata</i> (Sow.).
÷ <i>Ancilla mucronata</i> (Sow.).	<i>Macrocallista assimilis</i> (Hutt.).
<i>Marginella harrisi</i> Cossin.	<i>Corbula canaliculata</i> Hutt.
<i>Leucosyrinx alta</i> (Harris).*	<i>Corbula humerosa</i> Hutt.
<i>Leucosyrinx alta transenna</i> (Sut.).*	<i>Corbula kaiparaensis</i> Sut.
<i>Turris uttlei</i> Sut.	<i>Teredo heaphyi</i> Zitt.
<i>Exilia dalli</i> Sut.	

This list contains sixty species, of which nineteen are Recent, a percentage of 31·7. Of the above sixty species, over 60 per cent. are found in the Awamoan shell-bed at Target Gully.

Eight species have not previously been recorded from any horizon below the Awamoan. They are,—

<i>Cominella pulchra</i> Sut.	<i>Leucosyrinx alta transenna</i> (Sut.).
<i>Typhis maccoyi</i> Ten.-Woods.	<i>Bathytoma sulcata excavata</i> Sut.
÷ <i>Fulgoraria gracilis</i> (Swains.).	<i>Borsonia rudis</i> (Hutt.).
<i>Leucosyrinx alta</i> (Harris).	<i>Corbula kaiparaensis</i> Sut.

From the thin bed of glauconitic greensand at the base of the Waitaki stone Marshall and Uttley collected *Isis dactyla* Ten.-Woods.

On the palæontological evidence the so-called Waitaki stone at Otiake should be referred to the Awamoan instead of the Upper Hutchinsonian. (See footnote on previous page).

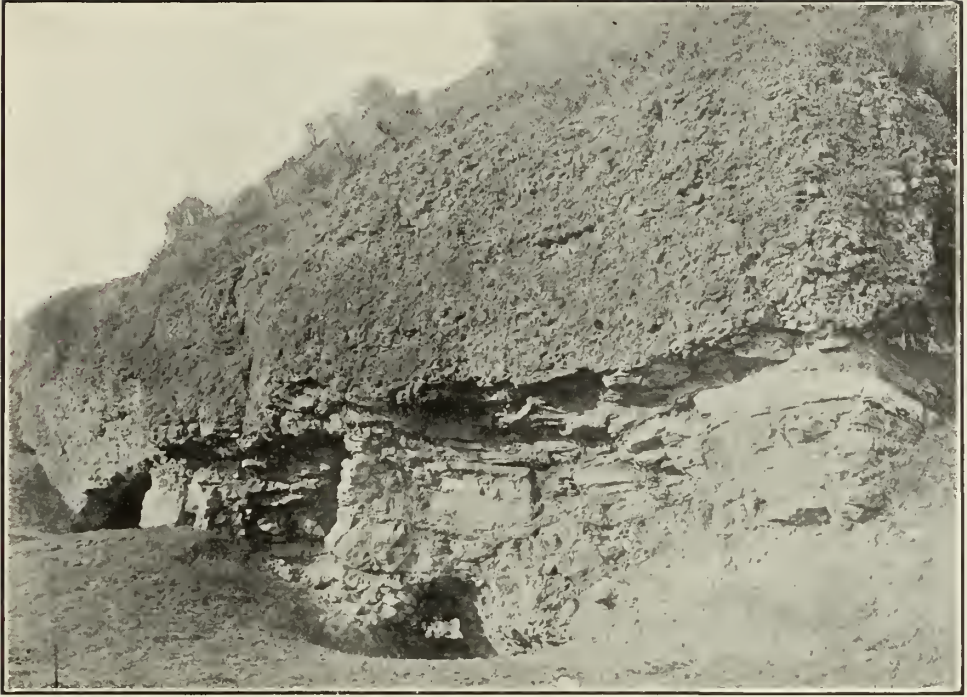
Section on Left Bank of Waitaki River, Wharekuri.

At this place Marshall and Uttley in 1914 made a large collection of molluscs from the "marly greensands" overlying the lignitic measures, and underlying the Waitaki stone. Their collection comprised—

<i>Turritella ambulacrum</i> Sow.	<i>Borsonia cincta</i> (Hutt.).
÷ <i>Turritella pagoda</i> Reeve.	<i>Borsonia rudis</i> (Hutt.).
÷ <i>Turritella symmetrica</i> Hutt.	<i>Exilia dalli</i> Sut.
÷ <i>Turritella carlottæ</i> Watson.	<i>Cylichnella enysi</i> (Hutt.).
<i>Struthiolaria cincta</i> Hutt.	<i>Xenophora</i> sp.

* *Turris* of hand-list.

PLATE X.



A. C. Gifford, photo.]

A. HUTCHINSON'S OLD LIMESTONE QUARRY, EDEN STREET, OAMARU.



A. C. Gifford, photo.]

B. HUTCHINSON'S OLD LIMESTONE QUARRY, EDEN STREET, OAMARU. OLIVE-GREEN
TUFFS UNDERLYING LIMESTONE ARE VISIBLE ON LEFT.

- ÷ *Calyptræa maculata* (Q. & G.).
Polinices gibbosus (Hutt.).
Polinices huttoni von Iher.
Polinices suturalis (Hutt.).
Sinum (Eunaticina) cinctum (Hutt.).
Cymatium minimum (Hutt.).
Epitonium lyratum (Zitt.).
Epitonium n. sp.
Niso n. sp.
Fusinus sp.
 ÷ *Siphonalia nodosa* (Mart.).
Siphonalia excelsa Sut.
Cominella exsculpta Sut.
Cominella pulchra Sut.
Alectrion socialis (Hutt.).
Cymbiola corrugata (Hutt.).
 ÷ *Fulgoraria gracilis* (Swains.).
Ancilla papillata (Tate).
 ÷ *Ancilla novæ-zelandiæ* (Sow.).
Marginella harrisi Cossm.
Turris utleyi Sut.
Drillia callimorpha Sut.
Surcula fusiformis (Hutt.).
Surcula hamiltoni (Hutt.).
Bathytoma sulcata excavata Sut.
- Dentalium mantelli* Zitt.
Dentalium solidum Hutt.
Leda semiteres Hutt.
 ÷ *Leda bellula* A. Ad.
 ÷ *Malletia australis* (Q. & G.)
Anomia trigonopsis Hutt.
 ÷ *Anomia walleri* Hect.
Glycymeris cordata (Hutt.).
Cucullæa attenuata Hutt.
 ÷ *Limopsis aurita* (Brocchi).
Limopsis zitteli von Iher.
Pecten chathamensis Hutt.
Pecten huttoni (Park).
 ÷ *Ostrea tatei* Sut.
 ÷ *Crassatellites obesus* (A. Ad.).
Venericardia pseutes Sut.
Loripes laminata Hutt.
 ÷ *Dosinia greyi* Zitt.
 ÷ *Macrocallista multistriata* (Sow.).
Chione meridionalis (Sow.).
Cardium patulum Hutt.
 ÷ *Psammobia lineolata* Gray.
Corbula humerosa Hutt.
Corbula canaliculata Hutt.
Teredo heaphyi Zitt.

Sixteen species in this list of sixty are Recent, a percentage of 26·7. The most abundant of these fossils are *Polinices huttoni*, *Cucullæa attenuata*, *Venericardia pseutes*, *Crassatellites obesus*, and, amongst the smaller shells, *Limopsis zitteli*.

The only other list of species of Mollusca from this locality is that given by the author.*

* *Trans. N.Z. Inst.*, vol. xxxvii, 1905, p. 525.

CHAPTER VIII.

AWAMOAN STAGE.

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CHARACTER OF ROCKS, AND DISTRIBUTION.

THE Awamoan rocks are strongly developed at All Day Bay (where they follow the Hutchinsonian conformably), in the Awamoia syncline, and at Pnkenri in the lower Waitaki. At the Rifle Butts they are conformable to the Hutchinsonian; but elsewhere in the Awamoia syncline their relationship to the underlying rocks cannot be seen, on account of the covering of Pleistocene silts and high-level gravels.

At the typical locality at the mouth of Awamoia Creek the rock-outcrops are now completely hidden by the recent accumulation of beach-sand and gravel. In 1905, when the author examined this place, the area of rock exposed between high- and low-water mark was about 4 square yards. In the early "seventies" the bare rock-platform was several acres in extent.

In the upper portion of Parson's Creek drainage-system there is a considerable area occupied by Awamoan strata. Here they lie in the middle of the Awamoia syncline.

The small area of Awamoan rocks at Pukeuri is isolated from all other rock-outcrops, but the palæontological evidence is so clear as to leave no room for doubt as to the stratigraphical position of the beds at that place.

Generally the Awamoan strata consist of blue or bluish-green marine sandy clays that in some places pass into bluish-green sea-muds, in other places into very soft sandstones. In most places they are interbedded at distant intervals with hard calcareous bands that are sometimes sandy, in others argillaceous and crowded with shells. In some places the hard bands are replaced by calcareous nodular concretionary masses and flaggy lenses, occurring in more or less well-defined horizons.

FAUNA OF AWAMOAN.

The molluscan fauna is rich and varied, comprising 289 species or more, of which ninety-five (or 32.9 per cent.) are living forms. The high proportion of living species would place the Awamoan at the summit of the Miocene.

The majority of the molluscs are littoral, and indicate conditions of deposition within the 10-fathom line.

Section at All Day Bay.

The stratigraphical relationship of the Awamoan to the Hutchinsonian is shown in Fig. 18 (page 56).

From the Awamoan beds at this place Marshall and Uttley* record the following molluscs:—

<i>Turritella cavershamensis</i> Harris.	<i>Marginella harrisi</i> Cossm.
<i>Polinices gibbosus</i> (Hutt.).	<i>Leucosyrinx alta</i> (Harris).†
<i>Cymatium</i> n. sp.	<i>Borsonia rudis</i> (Hutt.).
÷ <i>Phalium achatinum pyrum</i> (Lamk.).	<i>Dentalium mantelli</i> Hutt.
<i>Epitonium lyratum</i> (Zitt.).	÷ <i>Placunanomia zelandica</i> (Gray)
<i>Turbonilla oamarutica</i> Sut.	<i>Limopsis zitelli</i> von Iher.
<i>Mitra</i> n. sp.	÷ <i>Nucula hartvigiana</i> Pfr.
<i>Vexillum apicale</i> (Hutt.).	<i>Pecten huttoni</i> (Park).
<i>Typhis maccayi</i> Ten.-Woods.	<i>Lima colorata</i> Hutt.
÷ <i>Murex octogonus</i> Q. & G.	÷ <i>Crassatellites obesus</i> (A. Ad.).
<i>Cymbiola corrugata</i> (Hutt.).	÷ <i>Venericardia purpurata</i> (Desh.).
÷ <i>Ancilla novæ-zelandiæ</i> (Sow.).	<i>Macrocallista assimilis</i> (Hutt.).
<i>Ancilla</i> n. sp.	<i>Corbula pumila</i> Hutt.
<i>Marginella conica</i> Harris.	

Of the twenty-seven species enumerated above, seven (or 26 per cent.) are still living. Further collecting at this place will probably increase rather than decrease the proportion of Recent species. In any case, it is always unsafe to generalize as to age on the proportion of living forms in collections in which the total number of species is small.

Beds at Beach near Three Roads.

Overlying the greensands at this place there occurs an outcrop of blue sandy clays containing flat, thin, flaggy lenses of hard shelly rock. The actual junction between the Awamoan and Hutchinsonian is hidden by slope deposits. From the flaggy lenses in the Awamoan the author collected the following species:—

<i>Turritella semiconcava</i> Sut. (murrayana of hand-list).	<i>Modiolaria elongata</i> (Hutt.).
<i>Ampullina suturalis</i> (Hutt.).	<i>Ostrea wuellerstorfi</i> (?) Zitt.
<i>Surcula fusiformis</i> (Hutt.).	÷ <i>Crassatellites obesus</i> (A. Ad.).
÷ <i>Malletia australis</i> (Q. & G.).	<i>Crassatellites attenuatus</i> (?) (Hutt.).
<i>Arca subvelata</i> Sut.	÷ <i>Tellina glabrella</i> Desh. (plentiful).
<i>Cucullæa alta</i> Sow.	÷ <i>Zenatia acinaces</i> (Q. & G.).
÷ <i>Limopsis aurita</i> (Brocchi).	<i>Chione meridionalis</i> (Sow.) (plentiful).
<i>Limopsis catenata</i> Sut.	<i>Paphia curta</i> (Hutt.).
<i>Mytilus huttoni</i> Cossm. (<i>striatus</i> of hand-list).	<i>Cardium spatiosum</i> (?) Hutt.

Beds at Mouth of Awamoa Creek.

At this place the Awamoa beds form a flat shelving platform extending from high-water mark seaward. They occur about the middle of the Awamoa syncline, but are isolated from all other rocks of Oamaruan age. Collections were made from this place by Traill in 1869, by McKay in 1876, by the author in 1904, and by

* *Trans. N.Z. Inst.*, vol. xlvii, 1915, p. 384.

† *Turris altus* of hand-list.

Marshall and Uttley in 1912. The collections made by McKay in 1876 (locality No. 170) and by Marshall and Uttley in 1912, contained the following species:—

- | | |
|---|--|
| <i>Alectrion socialis</i> (Hutt.). | ÷ <i>Limopsis aurita</i> (Brocchi). |
| <i>Ampullina miocænica</i> Sut. | ÷ <i>Macrocallista multistriata</i> (Sow.). |
| ÷ <i>Ampullina undulata</i> (Hutt.). | <i>Macrocallista assimilis</i> (Hutt.). |
| <i>Ampullina drewi</i> (Murdoch). | <i>Mactra chrydara</i> Sut. |
| <i>Ampullina suturalis</i> (Hutt.). | ÷ <i>Malletia australis</i> (Q. & G.). |
| ÷ <i>Ancilla novæ-zealandiæ</i> (Sow.). | <i>Mangilia canaliculata</i> Sut. |
| <i>Ancilla papillata</i> (Tate). | <i>Marginella conica</i> Harris. |
| ÷ <i>Anomia walteri</i> Hect. | <i>Marginella harrisi</i> Cossm. |
| ÷ <i>Anomia huttoni</i> Sut. | ÷ <i>Modiolus australis</i> (Gray). |
| ÷ <i>Arca novæ-zealandiæ</i> Smith. | ÷ <i>Murex octogonus</i> (Q. & G.). |
| <i>Arca subvelata</i> Sut. | <i>Mytilus huttoni</i> Cossm. |
| ÷ <i>Calyptræa maculata</i> (Q. & G.). | ÷ <i>Natica zelandica</i> Q. & G. |
| ÷ <i>Calyptræa alta</i> (Hutt.). | ÷ <i>Nucula hartvigiana</i> Pfr. |
| <i>Cerithidea</i> n. sp. | <i>Ostrea</i> sp. |
| <i>Chione chiloensis truncata</i> Sut. | ÷ <i>Panope zelandica</i> Q. & G. |
| <i>Chione meridionalis</i> (Sow.). | <i>Pecten huttoni</i> (Park). |
| <i>Chione speighti</i> Sut. | <i>Phalium achatinum pyrum</i> (Lamk.). |
| ÷ <i>Cominella huttoni</i> Kobelt. | <i>Placunanomia incisura</i> Hutt. |
| <i>Corbula humerosa</i> Hutt. | <i>Polinices gibbosus</i> (Hutt.). |
| <i>Corbula kaiparaensis</i> Sut. | <i>Polinices ovatus</i> (Hutt.). |
| ÷ <i>Crassatellites obesus</i> (A. Ad.). | ÷ <i>Psammobia lineolata</i> Gray. |
| <i>Crassatellites attenuatus</i> (Hutt.). | ÷ <i>Serpulorbis siphon</i> (Lamk.). |
| ÷ <i>Crepidula monoxyla</i> (Less.). | ÷ <i>Siphonalia mandarina</i> (Duclos). |
| <i>Crepidula costata</i> (Sow.). | ÷ <i>Siphonalia dilatata</i> (Q. & G.). |
| <i>Crepidula gregaria</i> Sow. | <i>Siphonalia costata</i> (Hutt.). |
| <i>Cucullæa alta</i> Sow. | <i>Solariella stoliczkai</i> (Zitt.). |
| <i>Cucullæa alta</i> var. B. | <i>Struthiolaria cincta</i> Hutt. |
| <i>Cucullæa australis</i> (Hutt.). | <i>Surcula fusiformis</i> (Hutt.). |
| <i>Cylichnella enysi</i> (Hutt.). | ÷ <i>Terebra tristis</i> Desh. |
| <i>Cymatium minimum</i> (Hutt.). | ÷ <i>Trochus tiaratus</i> Q. & G. |
| <i>Cymbiola corrugata</i> (Hutt.). | <i>Leucosyrinx alta</i> (Harris). |
| <i>Cypræa</i> n. sp. | ÷ <i>Turritella rosea</i> Q. & G. |
| <i>Daphnella</i> n. sp. | ÷ <i>Turritella carlottæ</i> Wats. |
| <i>Dentalium mantelli</i> Zitt. | <i>Turritella concava</i> Hutt. |
| <i>Dentalium solidum</i> Hutt. | <i>Turritella semiconcava</i> Sut. |
| ÷ <i>Dosinia greyi</i> Zitt. | ÷ <i>Turritella symmetrica</i> Hutt. |
| <i>Drillia buchanani</i> (Hutt.). | <i>Turritella cavershamensis</i> Harris. |
| ÷ <i>Emarginula striatula</i> Q. & G. | <i>Typhis maccoyi</i> Ten.-Woods. |
| <i>Epitonium lyratum</i> (Zitt.). | <i>Venericardia pseudes</i> Sut.. |
| ÷ <i>Fusinus spiralis</i> (A. Ad.). | ÷ <i>Venericardia purpurata</i> (Desh.). |
| <i>Galeodea muricata</i> (Hutt.). | <i>Venericardia</i> cf. <i>inæqualis</i> Phil. |
| <i>Glycymeris globosa</i> (Hutt.). | <i>Vexillum linctum</i> (Hutt.). |
| <i>Hemiconus ornatus</i> (Hutt.). | ÷ <i>Zenatia acinaces</i> (Q. & G.). |
| <i>Lima colorata</i> Hutt. | |

Of the above eighty-seven species, thirty-two (or 36·8 per cent.) are still living.

Beds at Rifle Butts, South of Cape Wanbrow.

At this place the Awamoan beds follow the Hutchinsonian conformably (Plate IV). Collections were made here by Marshall and Uttley* in 1914, and by the author in 1916. The collection made by the author comprised the following species:—

<i>Alectrion socialis</i> (Hutt.).	<i>Pecten huttoni</i> (Park).
÷ <i>Calypttræa maculata</i> (Q. & G.).	<i>Pecten semiplicatus</i> Hutt.
<i>Chione meridionalis</i> (Sow.).	<i>Pecten yahliensis</i> Ten.-Woods.
÷ <i>Chione mesodesma</i> (Q. & G.).	<i>Phos cingulatus</i> (?) (Hutt.).
<i>Crassatellites attenuatus</i> (Hutt.).	<i>Pinna distans</i> Hutt.
<i>Cucullæa alta</i> Sow.	÷ <i>Placunanomia zelandica</i> (Gray).
<i>Cucullæa australis</i> (Hutt.).	<i>Polinices gibbosus</i> (Hutt.).
<i>Cylichnella enysi</i> (Hutt.).	<i>Siphonalia conoidea</i> Zitt.
<i>Dentalium solidum</i> Hutt.	<i>Surcula fusiformis</i> (Hutt.).
÷ <i>Dosinia greyi</i> Zitt.	<i>Surcula huttoni</i> Sut.
<i>Drillia awamoensis</i> (Hutt.).	÷ <i>Tellina glabrella</i> Desh.
<i>Drillia costifer</i> Sut.	<i>Leucosyrinx alta</i> (Harris).
÷ <i>Fulgoraria arabica</i> (Mart.).	<i>Turritella semiconcava</i> Sut.
<i>Lima colorata</i> Hutt.	÷ <i>Venericardia purpurata</i> (Desh.).
<i>Loripes laminata</i> Hutt.	<i>Venericardia pseutes</i> Sut.
<i>Macrocallista pareoraensis</i> Sut.	<i>Vexillum apicale</i> (Hutt.).
÷ <i>Malletia australis</i> (Q. & G.).	<i>Vexillum linctum</i> (Hutt.).
<i>Marginella conica</i> Harris.	÷ <i>Zenatia acinaces</i> (Q. & G.).
<i>Marginella harrisi</i> Cossin.	<i>Alcira</i> n. sp. (the same as that
÷ <i>Natica zelandica</i> Q. & G.	from Pukeuri).
÷ <i>Ostrea angasi</i> Sow.	<i>Erycina</i> n. sp.
<i>Pecten hutchinsoni</i> Hutt.	

The collection made by Marshall and Uttley contains twenty species not found by the author,—

<i>Turritella patagonica</i> Sow.	÷ <i>Marginella pygmaea</i> Sow.
<i>Turritella concava</i> Hutt.	÷ <i>Bathytoma albula</i> (Hutt.).
<i>Turritella</i> n. sp.	<i>Borsonia rudis</i> (Hutt.).
<i>Crepidula gregaria</i> Sow.	÷ <i>Mangilia protensa</i> (Hutt.).
<i>Ampullina suturalis</i> (Hutt.).	<i>Mangilia leptosoma</i> (Hutt.).
÷ <i>Polinices amphialus</i> (Wats.).	<i>Cucullæa attenuata</i> Hutt.
<i>Turbonilla oamarutica</i> Sut.	<i>Pecten scandula</i> Hutt.
÷ <i>Phalium achatinum pyrum</i> (Lamk.).	÷ <i>Venericardia difficilis</i> (Desh.).
<i>Siphonalia turrata</i> Sut.	÷ <i>Cytherea oblonga</i> (Hanley).
÷ <i>Ancilla nove-zealandicæ</i> (Sow.).	<i>Corbula caniculata</i> Hutt.

Turritella sturtii Tate, of Marshall and Uttley's collection, is almost certainly *T. semiconcava* Sut.

Of sixty-two species contained in the united lists, nineteen (or 30·6 per cent.) are Recent.

Ardgowan Shell-bed.

Collections were made at this place by T. Esdaile in 1886, by Marshall and Uttley in 1912, and by the author in 1916. Esdaile's collection is in the Geological

* *Trans. N.Z. Inst.*, vol. xlvii, 1915, p. 384.

Survey collections stored in the Dominion Museum. The collection made by the author in 1916 contains sixty-nine species, as follows:—

<i>Basilissa</i> n. sp.	<i>Surcula oamarutica</i> Sut.
<i>Basilissa</i> n. sp.	<i>Bathytoma sulcata</i> (Hutt.).
÷ <i>Serpulorbis siphon</i> (Lamk.).	<i>Maugilia canaliculata</i> Sut.
÷ <i>Siphonium planatum</i> Sut.	<i>Hemiconus ornatus</i> (Hutt.).
<i>Turritella cavershamensis</i> Harris.	÷ <i>Volvulella reflexa</i> (Hutt.).
<i>Turritella semiconcava</i> Sut.	<i>Dentalium mantelli</i> Zitt.
<i>Struthiolaria cincta</i> Hutt.	÷ <i>Dentalium nanum</i> Hutt.
÷ <i>Calyptrea alta</i> (Hutt.).	<i>Nucula sagittata</i> Sut.
<i>Calyptrea maccoyi</i> Sut.	÷ <i>Leda bellula</i> A. Ad. *
÷ <i>Calyptrea maculata</i> (Q. & G.).	÷ <i>Malletia australis</i> (Q. & G.).
÷ <i>Calyptrea maculata inflata</i> (Hutt.).	÷ <i>Anomia walteri</i> Hect.
÷ <i>Calyptrea tenuis</i> (Gray) (= <i>scutum</i>	<i>Placunanomia incisura</i> Hutt.
Less. of hand-list).	<i>Cucullæa alta</i> Sow.
÷ <i>Crepidula monoxyla</i> (Less.) (= <i>crepidula</i> (L.) of hand-list).	<i>Cucullæa australis</i> (Hutt.).
÷ <i>Natica zelandica</i> (Q. & G.).	÷ <i>Limopsis aurila</i> (Brocchi).
÷ <i>Polinices amphialus</i> (Wats.).	<i>Limopsis catenata</i> Sut.
<i>Polinices gibbosus</i> (Hutt.).	<i>Pecten huttoni</i> (Park).
÷ <i>Phalium achatinum pyrum</i> (Lamk.).	<i>Lima colorata</i> Hutt.
<i>Epitonium lyratum</i> (Zitt.).	<i>Crassatellites amplius</i> (Zitt.).
<i>Fusinus climacotus</i> Sut.	÷ <i>Crassatellites obesus</i> (A. Ad.).
<i>Vexillum rutidolomum</i> Sut.	÷ <i>Venericardia difficilis</i> (Desh.).
<i>Cominella pulchra</i> Sut.	<i>Venericardia pseutes</i> Sut.
<i>Alectrion socialis</i> (Hutt.).	÷ <i>Venericardia lutea</i> Hutt. (= <i>zelandica</i>
<i>Trophon lepidus</i> Sut.	(Desh.) of hand-list).
* <i>Merica (Aphera)</i> n. sp.	<i>Loripes laminata</i> Hutt.
÷ <i>Fulgovaria arabica</i> (Mart.).	÷ <i>Zenatia acinaces</i> (Q. & G.).
<i>Cymbiola corrugata</i> (Hutt.).	<i>Dosinia magna</i> Hutt.
<i>Ancilla papillata</i> (Tate).	<i>Cytherea sulcata</i> (?) (Hutt.).
<i>Marginella conica</i> Harris.	<i>Chione meridionalis</i> (Sow.).
<i>Marginella harrisi</i> Cossm.	<i>Paphia curta</i> (Hutt.).
<i>Drillia awamoensis</i> (Hutt.).	÷ <i>Psammobia stangeri</i> Gray.
<i>Drillia callimorpha</i> Sut.	<i>Corbula canaliculata</i> Hutt.
<i>Drillia</i> n. sp.	<i>Corbula humerosa</i> Hutt.
<i>Surcula fusiformis</i> (Hutt.).	<i>Corbula kaiparaensis</i> Sut.
<i>Surcula huttoni</i> (?) Sut.	<i>Panope worthingtoni</i> Hutt.
	<i>Teredo heaphyi</i> Zitt.

The additional species contained in the collection made by Marshall and Uttley are,—

÷ <i>Trochus tiaratus</i> Q. & G.	<i>Vexillum enysi</i> (Hutt.).
÷ <i>Turritella rosea</i> Q. & G.	<i>Ancilla papillata</i> (Tate).
<i>Struthiolaria tuberculata</i> Hutt.	÷ <i>Ancilla novæ-zelandiæ</i> (Sow.).
<i>Crepidula costata</i> (Sow.).	÷ <i>Maugilia sinclairi</i> (E. A. Smith).
÷ <i>Natica zelandica</i> Q. & G.	÷ <i>Cylichnella striata</i> (Hutt.).
<i>Ampullina suturalis</i> (Hutt.).	<i>Dentalium solidum</i> Hutt.
<i>Cymatium</i> cfr. <i>minimum</i> (Hutt.).	÷ <i>Nucula hartvigiana</i> Pfr.
<i>Leucosyrinx alta</i> (Harris).	<i>Glycymeris globosa</i> (Hutt.).

* Also from Target Gully she

÷ <i>Fusinus spiralis</i> (A. Ad.).	÷ <i>Pecten zelandiæ</i> Gray.
<i>Latirus brevirostris</i> (Hutt.).	<i>Crassatellites attenuatus</i> (Hutt.).
÷ <i>Siphonalia dilatata</i> (Q. & G.).	÷ <i>Venericardia purpurata</i> (Desh.).
÷ <i>Murex octogonus</i> Q. & G.	÷ <i>Diplodonta globularis</i> (Lamk.).
÷ <i>Terebra trisilis</i> Desh.	<i>Limopsis zitteli</i> von Iher.
<i>Typhis maccoyi</i> Ten.-Woods.	<i>Macrocallista assimilis</i> (Hutt.).
÷ <i>Trophon hanleyi</i> (Angas).	<i>Corbula pumila</i> Hutt.
÷ <i>Fulgoraria gracilis</i> (Swains.).	<i>Panope orbita</i> Hutt.

The united lists contain 101 species, of which thirty-eight (or 37·6 per cent.) are still living.

Parson's Creek Beds.

These beds consist of bluish-green sandy clays. They are well exposed in the bed and banks of Parson's Creek, close to the old Ardgowan homestead. The molluscs collected here were,—

÷ <i>Ancilla novæ-zelandiæ</i> (Sow.).	÷ <i>Macrocallista multistriata</i> (Sow.).
<i>Ancilla papillata</i> (Tate).	÷ <i>Malletia australis</i> (Q. & G.).
<i>Bathytoma sulcata excavata</i> Sut.	<i>Marginella harrisi</i> Cossm.
÷ <i>Calyptrea maculata</i> (Q. & G.).	÷ <i>Natica zelandica</i> Q. & G.
÷ <i>Calyptrea maculata inflata</i> (Hutt.).	<i>Nucula sagittata</i> Sut.
÷ <i>Calyptrea tenuis</i> Gray.	<i>Pecten huttoni</i> (Park.).
÷ <i>Crassatellites obesus</i> (A. Ad.).	<i>Sium</i> (<i>Eunaticina</i>) <i>cinctum</i> (Hutt.)
<i>Cymbiola corrugata</i> (Hutt.).	(= <i>Polinices cinctus</i> of hand-list).
÷ <i>Dentalium ecostatum</i> T. W. Kirk.	÷ <i>Sarepta obolella</i> (Tate).
<i>Dentalium mantelli</i> Zitt.	÷ <i>Siphonalia nodosa</i> (Mart.).
<i>Dentalium solidum</i> Hutt.	<i>Surcula fusiformis</i> (Hutt.).
÷ <i>Diplodonta globularis</i> (Lamk.).	<i>Teredo heaphyi</i> Zitt.
<i>Epitonium lyratum</i> (Zitt.).	<i>Leucosyrinx alta</i> (Harris).
<i>Galeodea senex</i> (Hutt.).	<i>Turritella semiconcava</i> Sut.
<i>Lima colorata</i> Hutt.	÷ <i>Venericardia difficilis</i> (Desh.).
÷ <i>Limopsis aurita</i> (Brocchi).	<i>Venericardia pseutes</i> Sut.
<i>Limopsis catenata</i> Sut.	÷ <i>Zenatia acinaces</i> (Q. & G.).

Of this small collection of thirty-three species, fifteen (or 45·5 per cent.) are Recent.

Note by Mr H. Suter on Sarepta obolella (Tate).

“*Sarepta obolella* (Tate) is new to New Zealand fauna. It is represented by one right valve only.

“1886. *Leda obolella* Tate: *Trans. Roy. Soc. S. Austr.*, vol. viii, p. 129, pl. v, figs. 3a, 3b.

“1897. *Nuculana obolella* Tate (sp.): Harris, *Cat. Tert. Moll. Brit. Mus.*, pt. i, p. 352.

“1901. *Sarepta* (?) *tellinæformis* Hedley: *Rec. Austr. Mus.*, vol. iv, No. 1, p. 26, fig. 8 in text.

“1902. *Sarepta obolella* Tate sp.: Hedley, *Mem. Austr. Mus.*, vol. iv, pt. 5, p. 295.

“1907. *Sarepta obolella* Tate: Verco, *Trans. Roy. Soc. S. Austr.*, vol. xxxi, p. 218.

“Fossil: Oligocene of Muddy Creek, Victoria. Type locality, Miocene of Parson's Creek, Oamaru, New Zealand.

“Recent: 41 to 75 fathoms, off the coast of New South Wales; 300 fathoms off Cape Jaffa, South Australia (Dr. Verco).

“Remark: The New Zealand valve is ovato-trigonal, and very likely stronger concentrically striated.

“Length, 6·7 mm.; height, 4·7 mm.; diameter, 1·5 mm.

“It is evidently not adult. Hedley remarks that the different stages of growth differ in the proportions of length to depth and height; adult specimens also vary in contour.”

Pukeuri Beds.

In the deep road-cutting near the railway-station there is a good exposure of yellowish-brown sandy strata, sufficiently compacted to constitute a soft sandstone. The constituent sand is very fine, and in places slightly glauconitic. The strike of the beds is north-east and south-west, and the dip south-east at angles varying from 8° to 12° . The cutting is 150 yards long, and it runs almost at right angles to the strike. The total thickness of strata exposed is 104 ft.

About the middle of the strata, in a well-defined horizon, there occur a few spheroidal concretions of hard calcareous sandstone, varying from 9 in. to 2 ft. in diameter. Some 20 ft. lower there is a horizon containing tabular and irregular-shaped masses of the same concretionary material, ranging up to 6 ft. in diameter. Most of the fossils occur in a band 6 in. thick, about 14 ft. below the summit of the series as exposed in the cutting, though a good many are present in the upper 25 ft. Below that, fossils are scarce and widely scattered, and comprise only a few genera, among which *Turritella*, *Hemiconus*, *Marginella*, and *Venericardia* are the most common.

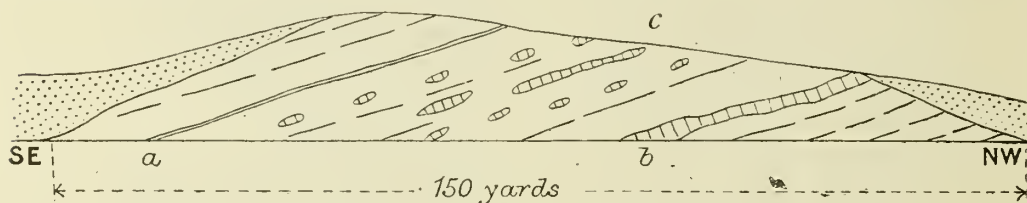


FIG. 40.—SECTION IN ROAD-CUTTING, PUKEURI.

a. Fossiliferous band. b. Hard calcareous sandstone layer. c. Hard concretionary masses.

Collections were made at this place by the author* in 1904. Marshall and Uttley† in 1912, and by the author in 1916 during the progress of the present survey.

The Pukeuri beds form an isolated outcrop about a mile distant from the nearest occurrence of any member of the Oamaruan. The palæontological evidence shows that Marshall and Uttley were right in referring these beds to the Awamoan.

The molluscs collected by the author in 1916 were,—

<i>Alectrion socialis</i> (Hutt.).	<i>Dentalium pareorensis</i> P. & S.
<i>Ampullina suturalis</i> (Hutt.).	<i>Drillia awamoensis</i> Hutt.
÷ <i>Ancilla novæ-zelandiæ</i> (Sow.).	÷ <i>Fulgoraria arabica</i> (Mart.).
<i>Ancilla papillata</i> (Tate).	<i>Fusinus spiralis dentatus</i> (Hutt.).
÷ <i>Calyptrea maculata</i> (Q. & G.).	<i>Galeodea senex</i> (Hutt.).
÷ <i>Calyptrea maculata inflata</i> (Hutt.).	§ <i>Hemiconus ornatus</i> (Hutt.).
‡ <i>Cominella pulchra</i> Sut.	<i>Lima colorata</i> Hutt.
<i>Corbula pumila</i> Hutt.	|| <i>Lima huttoni</i> Sut. var. nov.
÷ <i>Crassatellites obesus</i> (A. Ad.).	÷ <i>Limopsis aurita</i> (Brocchi).
<i>Crepidula gregaria</i> Sow.	÷ <i>Malletia australis</i> (Q. & G.).
<i>Cucullæa alta</i> Sow.	<i>Mangilia canaliculata</i> Sut.
<i>Cylichnella enysi</i> (Hutt.).	<i>Marginella conica</i> Harris.
<i>Cymatium minimum</i> (Hutt.).	<i>Marginella fraudulenta</i> Sut.
<i>Cymbiola corrugata</i> (Hutt.).	<i>Marginella harrisi</i> Cossm.
<i>Dentalium mantelli</i> Zitt.	÷ <i>Myodora crassa</i> (Stutchb.) (new as fossil).
÷ <i>Dentalium nanum</i> Hutt.	

* *Trans. N.Z. Inst.*, vol. xxxvii, 1905, pp. 518–519.

† *Trans. N.Z. Inst.*, vol. xlv, 1913, p. 303.

‡ No doubt *C. huttoni* of Marshall's list.

§ *Conus ornatus* Hutt. and *Conus trailii* Hutt. are undoubtedly identical; *Hemiconus ornatus* has priority.

|| Flat ribs, linear interstices.

÷ <i>Myodora pandoriformis</i> (Stutchb.) (new as fossil).	<i>Leucosyrinx alta</i> (Harris).
÷ <i>Natica zelandica</i> Q. & G.	<i>Turritella concava</i> Hutt.
<i>Pecten hochstetteri</i> Zitt.	<i>Turritella semiconcava</i> Sut.
÷ <i>Placunanomia zelandica</i> (Gray).	÷ <i>Venericardia difficilis</i> (Desh.).
* <i>Polinices gibbosus</i> (Hutt.).	† <i>Venericardia pseutes</i> Sut.
÷ <i>Protocardia pulchella</i> (Gray).	<i>Vexillum apicale</i> (Hutt.).
<i>Siphonalia excelsa</i> Sut.	<i>Vexillum fenestratum</i> Sut.
<i>Siphonalia turrita</i> Sut.	<i>Vexillum linctum</i> (Hutt.).
<i>Struthiolaria tuberculata</i> Hutt.	÷ <i>Zenatia acinaces</i> (Q. & G.).
<i>Surcula fusiformis</i> (Hutt.).	<i>Alcira</i> n. sp.; the same from Rifle Butts.
<i>Surcula pareoraensis</i> (Sut.).	

In addition to the fifty-two species contained in the above list, eleven species not found by the author were collected by Marshall and Uttley,—

÷ <i>Trochus tiaratus</i> Q. & G.	÷ <i>Nucula hartvigiana</i> Pfr.
÷ <i>Turritella rosea</i> Q. & G.	<i>Placunanomia incisura</i> Hutt.
÷ <i>Turritella carlotta</i> Watson.	<i>Pecten fischeri</i> Zitt.
÷ <i>Siphonalia dilatata</i> (Q. & G.).	<i>Macrocallista assimilis</i> (Hutt.).
÷ <i>Cylichnella striata</i> (Hutt.).	<i>Chione meridionalis</i> (Sow.).
<i>Dentalium solidum</i> Hutt. (= <i>D. opacum</i> of Marshall and Uttley's list).	

Of the sixty-three species contained in the united lists, twenty-one species (or 33·3 per cent.) are Recent.

Target Gully Shell-bed, Oamaru.

This bed erops out on the Town Belt reserve. The exposure is only a few yards long, and the thickness of the deposit as shown by excavations made by the author is 6 ft. (Plate X.)

The material consists mainly of shells mixed with sand. There is a little glauconite present, doubtless derived from the underlying greensands. Most of the shells are broken, and many of them are water-worn. The deposit lies against a low eliff eroded in the underlying calcareous sandstone that closes the Hutchinsonian (Fig. 35). Rolled water-worn fragments of *Pachymagas parki* (Hutton) that occur in the shell-bed were probably derived from the eroded greensands lying below. It is not improbable that some of the molluscs were derived from the same source.

This shell-bed is one of the richest fossil localities in New Zealand. Of the great assemblage of molluscs found in it, some are forms usually found in 200 fathoms of water, while many are littoral shells. The great mixture of shells and the character of the deposit would tend to show that it was formed as a shell-bank in comparatively shallow water. Besides molluscs and brachiopods there are present fish-teeth, crab-remains, echinoderm plates and spines, corals, polyzoans, and Foraminifera.

Marshall and Uttley were the first to collect molluscs here. In 1912,‡ 1913,§ and 1914|| they made many fine collections. Altogether they collected about 160 species.¶ The collection made by the author in 1916 added another fifty species or more, of which twenty-two are new species. Some of the others are new as fossils, some are new to the Mioene, and some are new to the New Zealand fauna.

* *P. ovatus* in Marshall's list (?).

† *V. australis* in Marshall's list (?).

‡ *Trans. N.Z. Inst.*, vol. xlv, 1913, pp. 301–303.

§ *Trans. N.Z. Inst.*, vol. xlv, 1914, pp. 279–280.

|| *Trans. N.Z. Inst.*, vol. xlvii, 1915, pp. 378–38

¶ *Loc. cit.*, p. 879.

The united lists contain 212 species, of which seventy-one species (or 33·5 per cent.) are Recent. This is the largest number of molluscs hitherto obtained from any fossiliferous horizon in New Zealand. It is almost certain that further excavation will bring to light many species not contained in the following list:—

LIST OF MOLLUSCS COLLECTED AT SHELL-BED, TARGET GULLY, OAMARU, BY MARSHALL, UTTLEY, AND PARK.

- | | |
|---|--|
| ÷ <i>Schismope atkinsoni</i> (Ten.-Woods). | <i>Crepidula gregaria</i> Sow. |
| ÷ <i>Emarginula striatula</i> Q. & G. | <i>Crepidula striata</i> (Hutt.). |
| ÷ <i>Subemarginula intermedia</i> (Reeve). | ÷ <i>Natica australis</i> (Hutt.). |
| ÷ <i>Trochus chathamensis</i> (Hutt.). | ÷ <i>Natica zelandica</i> Q. & G. |
| ÷ <i>Trochus tiaratus</i> Q. & G. | <i>Polinices gibbosus</i> (Hutt.). |
| ÷ <i>Monodonta coracina</i> (Troschel). | <i>Sinum cinctum</i> (Hutt.). [<i>Polinices</i> .] |
| ÷ <i>Cantharidus tenebrosus</i> A. Ad. | <i>Sinum carinatum</i> (Hutt. [<i>Ampul-</i> |
| <i>Calliostoma</i> n. sp. | <i>lina</i> .] |
| <i>Basilissa</i> n. sp. | <i>Ampullina</i> (<i>Megatylotus</i>) <i>suturalis</i> |
| <i>Lissospira exigua</i> Sut. | (Hutt.). |
| <i>Circulus helicoides</i> (Hutt.). | ÷ § <i>Trivia avellanoides</i> (McCoy). |
| <i>Circulus politus</i> Sut. | <i>Erato neozelanica</i> Sut. |
| ÷ <i>Leptothyra fluctuata</i> (Hutt.) | <i>Cymatium minimum</i> (Hutt.). |
| ÷ * <i>Rissoina emarginata</i> (Hutt.). | <i>Heliacus imperfectus</i> Sut. |
| <i>Rissoina</i> n. sp. | ÷ † <i>Heliacus variegatus</i> (Gmel.). |
| <i>Besanconia</i> (<i>Ataxocerithium</i>) n. sp. | ÷ <i>Ancilla australis</i> (Sow.). |
| <i>Besanconia</i> (<i>Ataxocerithium</i>) n. sp. | ÷ <i>Ancilla novae-zelandiae</i> (Sow.). [<i>A.</i> |
| † <i>Seila bulbosa</i> Sut. | <i>bicolor</i> .] |
| <i>Cerithiopsis æquicincta</i> Sut. | <i>Ancilla hebera</i> (Hutt.). |
| <i>Cerithiella fidicula</i> Sut. [<i>Newtoni-</i> | <i>Ancilla papillata</i> (Tate). |
| <i>ella</i> .‡] | <i>Marginella conica</i> Harris. |
| ÷ † <i>Triphora lutea</i> Sut. | <i>Marginella fraudulenta</i> Sut. |
| <i>Vernicularia</i> n. sp. | <i>Marginella harrisi</i> Cossm. |
| ÷ <i>Serpulorbis siphon</i> (Lamk.). | <i>Marginella</i> (<i>Glabella</i>) n. sp. |
| ÷ <i>Siphonium planatum</i> Sut. | <i>Turris regius</i> Sut. (?) |
| ÷ † <i>Siliquaria weldii</i> Ten.-Woods. | <i>Leucosyrinx alta</i> (Harris). [<i>Turris</i> .] |
| ÷ <i>Turritella carlottæ</i> Watson. | <i>Leucosyrinx alta transenna</i> (Sut.). |
| <i>Turritella concava</i> Hutt. | [<i>Turris</i> .] |
| <i>Turritella semiconcava</i> Sut. | <i>Drillia avamoensis</i> (Hutt.). |
| <i>Turritella patagonica</i> Sow. | <i>Drillia callimorpha</i> Sut. |
| ÷ <i>Turritella rosea</i> Q. & G. | <i>Drillia costifer</i> Sut. |
| <i>Mesalia striolata</i> (Hutt.). [<i>Eglisia</i> .] | <i>Drillia imperfecta</i> Sut. |
| <i>Struthiolaria cincta</i> Hutt. | <i>Drillia</i> n. sp. |
| <i>Struthiolaria tuberculata</i> Hutt. | <i>Drillia</i> n. sp. |
| ÷ <i>Calyptrea maculata</i> (Q. & G.). | <i>Surcula fusiformis</i> (Hutt.). |
| ÷ <i>Calyptrea maculata inflata</i> (Hutt.). | <i>Surcula pareoraensis</i> Sut. (?) |
| <i>Calyptrea maccoyi</i> Sut. | <i>Surcula</i> n. sp. |
| ÷ <i>Crepidula costata</i> (Sow.). | ÷ <i>Bathytoma albula</i> (Hutt.). |
| ÷ <i>Crepidula monoxylla</i> (Less.). [<i>C.</i> | <i>Bathytoma antecostata</i> Sut. |
| <i>crepidula</i> .] | <i>Bathytoma perlata</i> Sut. |
| <i>Crepidula densistria</i> Sut. | <i>Bathytoma sulcata</i> (Hutt.). |

* No spiral striæ. New for the Miocene. brackets refer to H. Suter's hand-list (1915).

† New as a fossil.

‡ This and other names added in § New to New Zealand fauna.

LIST OF MOLLUSCS COLLECTED AT SHELL-BED, ETC.—*continued*.

- Mangilia canaliculata* Sut.
 ÷ * *Mangilia dictyota* (Hutt.).
Mangilia gracilentia Sut.
Mangilia infelix Sut.
Mangilia leptosoma (Hutt.).
Mangilia præcophinoides Sut.
Mangilia pukeuriensis Sut.
Mangilia tenuilirata Sut.
Borsonia rudis (Hutt.). [*Mangilia*.]
Borsonia brachyspira Sut.
Hemiconus ornatus (Hutt.). [*H. trailli*.]
Terebra costata Hutt.
Terebra orycta Sut.
Ringicula uniplicata Hutt.
Tornatina n. sp.
 ÷ *Volvulella reflexa* (Hutt.).
Cylichnella enysi (Hutt.).
Cylichnella soror Sut.
 ÷ *Dentalium ecostatum* T. W. Kirk.
Dentalium mantelli Zitt.
 ÷ *Dentalium nanum* Hutt.
Dentalium solidum Hutt.
 ÷ *Nucula nitidula* A. Ad.
Nucula sagittata Sut.
Leda semiteres Hutt.
 ÷ *Malletia australis* (Q. & G.).
 ÷ *Anomia huttoni* Sut.
Placunanomia incisura Hutt.
 ÷ *Placunanomia zelandica* (Gray).
Epitonium lyratum (Zitt.). [*E. rugulosum lyratum*.]
 ÷ *Epitonium zeledori* (Dkr.).
Eglsia n. sp.
Turbonilla (Pyrgiscus) oamarutica Sut.
Turbonilla (Mormula) prisca Sut.
 ÷ *Turbonilla zelandica* (Hutt.).
 ÷ † *Odostomia pudica* Sut.
 ÷ *Odostomia (Pyrgulina) rugata* Hutt.
Odostomia n. sp.
Odostomia n. sp.
 † *Eulima obliqua* (Hutt.).
 ÷ *Megalatractus maximus* (Tryon).
Fusinus climacotus Sut.
 ÷ *Fusinus spiralis* (A. Ad.).
Fusinus n. sp.
- Latirus acuticingulatus* Sut.
Latirus brevirostris (Hutt.).
Latirus compactus Sut.
Latirus elatior Sut.
Latirus n. sp.
Streptochetus n. sp.
Mitra (Cancilla) armorica Sut.
Vexillum fenestratum Sut.
 ÷ *Vexillum marginatum* (Hutt.).
Vexillum rutidolomum Sut.
 ÷ *Siphonalia caudata* (Q. & G.).
Siphonalia conoidea (Zitt.).
Siphonalia costata (Hutt.).
 ÷ *Siphonalia dilatata* (Q. & G.).
Siphonalia excelsa Sut.
Siphonalia nodosa zitteli Sut.
Siphonalia n. sp.
Euthria strophora Sut.
Cominella intermedia Sut.
Cominella ordinatis Hutt.
Cominella pulchra Sut.
Alectrion socialis (Hutt.).
 ÷ *Murex angasi* (Crosse).
 ÷ *Murex octogonus* Q. & G.
 ÷ *Trophon hanleyi* (Angas).
Trophon lepidus Sut.
Trophon minutissimus Sut.
Typhis maccayi Ten.-Woods.
Acteon præcursoria Sut. [*Admete*.]
Sveltia n. sp.
Merica n. sp.
Merica n. sp.
Merica n. sp.
Merica (Aphera) n. sp.
 † *Anachis pisaniopsis* (Hutt.).
 ÷ *Fulgoraria arabica* (Mart.).
 ÷ *Fulgoraria arabica elongata* (Swains.).
 ÷ *Fulgoraria gracilis* (Swains.).
Cymbiola corrugata (Hutt.).
 ÷ *Arca novæ-zelandiæ* Smith. [*A. decussata*.]
Arca subvelata Sut.
Glycymeris subglobosa Sut.
Cucullæa alta Sow.
Cucullæa australis (Hutt.).
Limopsis catenata Sut.
Limopsis zitteli Ihering.

* Slender form. New for the Miocene.

† New to the Miocene.

LIST OF MOLLUSCS COLLECTED AT SHELL-BED, ETC.—*continued*.

- Mytilus huttoni* Cossin. [*M. striatus*.] ÷ *Zenatia acinaces* (Q. & G.).
 ÷ *Modiolus australis* (Gray). ÷ *Dosinia greyi* Zitt.
Pecten burnetti Zitt. *Dosinia magna* Hutt.
Pecten huttoni (Park). ÷ *Maerocallista multistriata* (Sow.).
 ÷ *Pecten radiatus* Hutt. ÷ *Cytherea oblonga* (Hanley).
Hinnites trailli Hutt. ÷ *Cytherea subsulcata* (Sut.).
 ÷ *Lima bullata* (Born). *Cytherea sulcata* (Hutt.).
Lima colorata Hutt. *Chione meridionalis* (Sow.).
 ÷ *Ostrea angasi* Sow. ÷ *Chione mesodesma* (Q. & G.)
Ostrea nelsoniana Zitt. ÷ *Chione yatei* (Gray).
Crassatellites amplus (Zitt.). *Paphia curta* (Hutt.)
Crassatellites attenuatus (Hutt.) *Cardium patulum* Hutt.
 ÷ *Crassatellites obesus* (A. Ad.). *Protocardia sera* Hutt.
Cuna n. sp. *Chama huttoni* Hect.
 ÷ *Venericardia difficilis* (Desh.). ÷ *Psammobia lineolata* Gray.
Venericardia pseutes Sut. *Corbula canaliculata* Hutt.
 ÷ *Venericardia lutea* (Hutt.). [*V. ze-* *Corbula humerosa* Hutt.
landica.] *Corbula kaiparaensis* Sut.
Venericardia subintermedia Sut. n. var. *Corbula pumila* Hutt.
 ÷ *Divaricella cumingi* (Ad. & Ang.). *Barnea* n. sp.
 ÷ *Loripes concinna* Hutt. *Teredo heaphyi* Zitt.
Loripes laminata Hutt. ÷ *Myodora subrostrata* Smith.
 ÷ *Diplodonta globularis* (Lamk.). ÷ *Chamostrea albida* (Lamk.).
 ÷ *Tellina glabrella* Desh.
-



A. C. Gifford, photo.

TARGET GULLY SHELL-BED, AWAMOAN.

CHAPTER IX.

OAMARUIAN MOLLUSCA AND BRACHIOPODA.

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OAMARUIAN MOLLUSCA.

Summary of Molluscs.

					Genera.	Species.	Recent Species.	Percentage of Recent Species.
Awamoan	..	..	..	..	122	293	97	33.1
Hutchinsonian	..	..	..	..	82	165	55	33.3
Ototaran	..	..	..	..	52	95	28	29.5
Waiarekan	..	..	..	..	66	114	32	28.1
Ngaparan	..	..	..	..	..	..	..	..
Total Oamaruan Mollusca ..					157	417	126	30.2
Hutchinsonian (Upper or Waitakian ..					75	142	48	33.8
(Lower					35	57	13	22.8
Waiarekan (Upper					42	64	20	31.25
(Lower or Bortonian					45	64	15	23.4

Alphabetical List of Genera and Species in Oamaruan.

THE molluscs found in the marine members of the Oamaruan are shown in the following tabulated statement, arranged in alphabetical order:—

Genus and Species.					Ngaparan (Lignitic) Stage.	Waiarekan Stage.		Ototaran Stage.	Hutchinsonian Stage.		Awamoan Stage.
						Lower or Bortonian.	Upper.		Lower.	Upper.	
<i>Acteon præcursorius</i> Sut.	..	..	..	..	..	..	..	..	..	X	..
<i>Alcira</i> n. sp.	..	..	..	..	..	..	..	..	..	..	X
<i>Alectrion socialis</i> (Hutt.)	..	..	..	..	..	..	..	..	..	X	X
<i>Ampullina drewi</i> (Murd.)	..	..	..	..	..	..	..	..	..	..	X
— <i>miocænica</i> Sut.	..	..	..	..	..	..	..	..	..	..	X
— <i>suturalis</i> (Hutt.)	..	..	..	..	..	..	..	X	X	X	X
÷ — <i>undulata</i> (Hutt.)	..	..	..	..	..	..	..	..	..	X	X
<i>Amusium zitteli</i> (Hutt.)	..	..	..	..	..	..	X	..	..	..	..

Alphabetical List of Genera and Species in Oamaruan—continued.

Genus and Species.	Ngaparan (Lignite) Stage.	Waiarekan Stage.		Otataran Stage.	Hutchinsonian Stage.		Awamoan Stage.
		Lower or Bortonian.	Upper.		Lower.	Upper.	
<i>Anachis pisanioipsis</i> (Hutt.)	..	..	..	..	..	..	X
÷ <i>Ancilla australis</i> (Sow.)	..	..	..	..	..	..	X
÷ — <i>australis pyramidalis</i> (Reeve)	..	..	..	..	..	..	X
— <i>hebera</i> (Hutt.)	..	..	X	..	..	X	X
÷ — <i>mucronata</i> (Sow.)	..	..	..	..	..	X	..
÷ — <i>novæ-zelandiæ</i> Sow.	..	..	..	..	..	X	X
— <i>papillata</i> (Tate)	..	..	..	..	X	X	X
— <i>waikopiroensis</i> Sut. n. sp.	..	..	..	..	..	..	X
— n. sp.	..	..	..	..	..	..	X
÷ <i>Anomia huttoni</i> Sut.	..	X	..	X	..	..	..
— <i>trigonopsis</i> Hutt.	..	..	..	..	..	X	..
÷ — <i>walteri</i> Hect.	..	..	..	..	X	X	X
÷ <i>Arca novæ-zelandiæ</i> Smith	..	..	..	X	..	X	X
— <i>subvelata</i> Sut.	..	..	..	..	..	X	X
<i>Astarte australis</i> Hutt.	..	..	..	..	..	X	..
÷ <i>Astræa heliotropium</i> (Mart.)	..	..	X	X	..	..	..
<i>Athleta necopinata</i> Sut.	..	X	..	..	..	..	..
<i>Atrina distans</i> (Hutt.)	..	..	..	..	..	..	X
<i>Aturia australis</i> McCoy	..	..	..	X	..	..	..
<i>Barnea</i> n. sp.	..	..	..	..	..	..	X
<i>Basilissa</i> n. spp. (3)	..	..	..	..	..	..	X
÷ <i>Bathytoma albula</i> (Hutt.)	..	..	..	..	..	..	..
— <i>antecostata</i> Sut.	..	..	..	..	..	..	X
— <i>perlata</i> Sut.	..	..	..	..	..	..	X
— <i>sulcata</i> (Hutt.)	..	..	..	..	..	..	X
— <i>sulcata excavata</i> Sut.	..	..	..	..	..	X	X
<i>Bezanconia</i> n. spp. (2)	..	..	..	..	..	..	X
<i>Borsonia cincta</i> (Hutt.)	..	..	..	..	..	..	X
— <i>rudis</i> (Hutt.)	..	..	..	..	..	X	X
— <i>brachyspira</i> Sut.	..	..	..	..	..	..	X
÷ <i>Calliostoma pellucidum</i> (Val.)	..	..	..	..	..	X	..
— n. sp.	..	..	X	..	..	..	..
— n. sp.	..	..	..	..	..	..	X
÷ <i>Calyptoræa alta</i> (Hutt.)	..	X	..	..	..	X	X
— <i>inflata</i> Hutt.	..	..	..	..	..	..	X
— <i>maccoyi</i> Sut.	..	..	..	..	..	X	X
÷ — <i>maculata</i> (Q. & G.)	..	..	X	X	..	X	X
÷ — <i>maculata inflata</i> (Hutt.)	..	..	..	X	..	..	X
÷ — <i>tenuis</i> (Gray)	..	..	..	..	..	..	X
÷ <i>Cantharidus tenebrosus</i> A. Ad.	..	..	..	..	..	X	X
÷ <i>Capulus australis</i> (Lamk.)	..	..	..	X	X	..	..
÷ <i>Cardita calyculata</i> (L.)	..	..	X	..	..	..	..
<i>Cardium huttoni</i> von Iher.	..	X	X	..	..	..	..
— <i>patulum</i> Hutt.	..	..	..	X	X	X	X
— <i>spatiosum</i> Hutt.	..	X	..	X	X	..	X
— <i>waitakiense</i> Sut.	..	X	..	X	..	..	..
— n. spp. (2)	..	..	X	..	..	..	..
— n. sp.	..	..	..	X	..	..	..
<i>Cerithidea</i> n. sp.	..	..	..	..	..	..	X
<i>Cerithiella fidicula</i> Sut.	..	..	..	..	..	..	X
<i>Cerithiopsis æquicincta</i> Sut.	..	..	..	..	..	..	X

Alphabetical List of Genera and Species in Oamaruan—continued.

Genus and Species.	Ngaparan (Lignitic) Stage.	Waiarekan Stage.		Ototoaran Stage.	Hutchinsonian Stage.		Awamoan Stage.
		Lower or Bortonian.	Upper.		Lower.	Upper.	
<i>Chama huttoni</i> Hect.	..	..	..	..	..	..	X
÷ <i>Chamostrea albida</i> (Lamk.)	..	..	..	..	..	..	X
<i>Chione chiloensis truncata</i> Sut.	..	X	..	..	..	..	X
— <i>meridionalis</i> (Sow.)	..	X	X	X	X	X	X
÷ — <i>mesodesma</i> (Q. & G.)	..	..	..	X	..	..	X
— <i>speighti</i> Sut.	..	..	..	..	..	..	X
÷ — <i>spissa</i> Desh.	..	..	..	X	..	..	..
÷ — <i>yatei</i> (Gray)	..	..	..	..	..	..	X
<i>Circulus helicoides</i> (Hutt.)	..	..	..	..	..	..	X
— <i>politus</i> Sut.	..	..	..	..	..	..	X
<i>Clavagella</i> n. sp. (genus new to N.Z. fauna)	..	..	..	X	..	..	..
<i>Clio annulata</i> (Tate) (new to N.Z. fauna)	..	..	X	..	..	..	..
— <i>rangiana</i> (Tate)	..	X	..	..	..	..	..
<i>Colubraria</i> n. sp. (genus new to N.Z.)	..	..	..	X	..	..	..
<i>Cominella exsculpta</i> Sut.	..	..	..	..	..	X	..
÷ — <i>huttoni</i> Kobelt	..	..	..	..	..	..	X
— <i>intermedia</i> Sut.	..	..	..	..	..	..	X
— <i>ordinatus</i> Hutt.	..	..	..	..	..	..	X
— <i>pulchra</i> Sut.	..	..	..	..	..	X	X
<i>Corbula canaliculata</i> Hutt.	..	X	..	..	..	X	X
— <i>humerosa</i> Hutt.	..	..	..	..	..	X	X
— <i>kaiparaensis</i> Sut.	..	..	..	..	..	X	X
— <i>pumila</i> Hutt.	..	..	..	..	..	X	X
<i>Crassatellites amplius</i> (Zitt.)	..	X	X	..	..	..	X
— <i>attenuatus</i> (Hutt.)	..	..	..	..	..	..	X
÷ — <i>obesus</i> (A. Ad.)	..	..	X	X	X	X	X
÷ <i>Crepidula costata</i> (Sow.)	..	..	..	..	..	..	X
— <i>densistria</i> Sut.	..	..	X	..	..	..	X
— <i>gregaria</i> Sow.	..	X	..	..	..	X	X
÷ — <i>monoxyla</i> (Less.)	..	..	..	X	..	X	X
— <i>striata</i> (Hutt.)	..	..	..	..	..	X	X
<i>Cucullæa alta</i> Sow.	..	X	..	X	X	X	X
— <i>alta</i> var. B. Hutt.	..	..	..	..	..	..	X
— <i>attenuata</i> Hutt.	..	..	..	..	..	X	X
— <i>australis</i> (Hutt.)	..	X	..	..	..	..	X
<i>Cuna</i> n. sp.	..	..	..	..	..	..	X
<i>Cuspidaria</i> n. sp.	..	..	X	..	..	..	..
<i>Cylichnella enysi</i> (Hutt.)	..	X	X	..	..	X	X
— <i>soror</i> Sut.	..	X	..	..	..	X	X
÷ — <i>striata</i> (Hutt.)	..	..	..	..	..	..	X
<i>Cymatium minimum</i> (Hutt.)	..	..	..	X	..	X	X
— n. sp.	..	..	..	..	..	..	X
<i>Cymbiola corrugata</i> (Hutt.)	..	..	..	X	X	X	X
<i>Cypræa ovulatella</i> Tate	..	..	..	X	..	..	..
— <i>trelissickensis</i> Sut.	..	..	..	..	X	..	..
— n. sp.	..	..	..	..	..	..	X
<i>Cytherea chariessa</i> Sut.	..	..	..	X	..	X	..
÷ — <i>oblonga</i> (Hanley)	..	..	..	..	..	X	X
÷ — <i>subsulcata</i> (Sut.)	..	..	X	..	..	..	X
— <i>sulcata</i> (Hutt.)	..	..	X	X	..	..	X
— n. sp.	..	..	..	..	..	X	..

Alphabetical List of Genera and Species in Oamaruan—continued.

Genus and Species.	Ngaparan Stage.	Waiarekan Stage.		Ototaran Stage.	Hutchinsonian Stage.		Awamoan Stage.
		Lower or Bortonian.	Upper.		Lower.	Upper.	
<i>Daphnella</i> n. sp.	..	..	..	..	..	..	X
÷ <i>Dentalium ecostatum</i> T. W. Kirk	..	..	..	..	..	..	X
— <i>mantelli</i> Zitt.	..	..	..	X	..	X	X
÷ — <i>nanum</i> Hutt.	..	..	..	..	..	..	X
— <i>pareorensis</i> Pilsbry and Sharp	..	..	..	..	..	..	X
— <i>solidum</i> Hutt.	..	..	X	X	X	X	X
÷ — <i>zelandicum</i> Sow.	..	..	..	..	..	..	X
— n. sp.	..	..	X	..	..	..	..
÷ <i>Diplodonta globularis</i> (Lamk.)	..	..	..	..	X	X	X
÷ — <i>zelandica</i> (Gray)	..	..	X	X	..	X	..
÷ <i>Divaricella cumingi</i> (Ad. & Ang.)	..	..	..	..	..	X	X
÷ <i>Dosinia cærulea</i> (Reeve)	..	..	X	..	..	..	..
÷ — <i>grayi</i> Zitt.	..	X	..	X	..	X	X
— <i>magna</i> Hutt.	..	X	..	..	..	..	X
<i>Drillia awamoensis</i> (Hutt.)	..	..	..	..	..	..	X
— <i>buchanani</i> (Hutt.)	..	..	..	..	..	..	X
— <i>callimorpha</i> Sut.	..	..	..	..	..	X	X
— <i>costifer</i> Sut.	..	..	..	..	..	..	X
— <i>imperfecta</i> Sut.	..	..	..	..	..	..	X
— n. spp. (3)	..	..	..	..	..	..	X
÷ <i>Emarginula striatula</i> Q. & G.	..	..	..	..	..	..	X
— <i>wanonenensis</i> Harris	..	..	X	X	..	X	..
<i>Epitonium lyratum</i> (Zitt.)	..	..	X	X	X	X	X
— <i>nympha</i> (Hutt.)	..	..	..	X	..	..	..
÷ — <i>zelebori</i> (Dkr.)	..	..	..	X	X	X	X
— n. sp.	..	..	..	..	..	X	..
— n. sp.	..	..	..	..	X	..	..
— n. sp.	..	..	..	X	..	..	..
<i>Erato neozelanica</i> Sut.	..	..	..	..	..	..	X
<i>Erycina</i> n. sp.	..	..	..	..	..	..	X
<i>Eulima obliqua</i> (Hutt.)	..	..	..	..	..	..	X
<i>Euthria media</i> (Hutt.)	..	..	..	X	..	..	..
— <i>strophora</i> Sut.	..	..	..	..	..	..	X
— sp.	..	..	..	..	..	X	..
<i>Euthriofusus spinosus</i> Sut.	..	..	X	..	..	..	..
<i>Exilia crassicostata</i> Sut.	..	..	..	..	..	..	X
— <i>dalli</i> Sut.	..	..	..	..	..	X	..
<i>Ficus transennus</i> Sut.	..	..	..	X	..	..	..
÷ <i>Fulgoraria arabica</i> (Mart.)	..	..	..	..	..	..	X
÷ — <i>arabica elongata</i> (Swains.)	..	..	..	..	..	..	X
— <i>arabica turrita</i> Sut.	..	..	X	..	..	..	..
÷ — <i>gracilis</i> (Swains.)	..	..	..	..	..	X	X
<i>Fusinus climacotus</i> Sut.	..	..	..	..	..	..	X
— <i>solidus</i> Sut.	..	..	..	..	X	..	..
÷ — <i>spiralis</i> (A. Ad.)	..	..	..	..	..	..	X
— <i>spiralis dentatus</i> (Hutt.)	..	..	..	..	..	..	X
— n. spp. (3)	..	..	..	..	..	..	X
— n. sp.	..	..	..	X	..	..	..
— sp.	..	..	..	..	..	X	..
÷ <i>Gadina conica</i> Angas	..	..	..	X	..	..	..
<i>Galeodea muricata</i> (Hect.)	..	..	..	..	..	..	X

Alphabetical List of Genera and Species in Oamaruan—continued.

Genus and Species.	Ngaparan (Lignite) Stage.	Waiarekan Stage.		Otataran Stage.	Hutchinsonian Stage.		Awamoan Stage.
		Lower or Bortonian.	Upper.		Lower.	Upper.	
<i>Galeodea senex</i> (Hutt.)	..	..	..	..	X	..	X
<i>Galeodes</i> n. sp.	..	X	..	..	..	..	..
<i>Glycymeris cordata</i> (Hutt.)	..	..	..	..	X	X	..
— <i>globosa</i> (Hutt.)	..	..	..	..	..	..	X
÷ — <i>laticostata</i> (Q. & G.)	..	..	X	X	X	..	X
— <i>subglobosa</i> Sut.	..	..	..	..	..	..	X
<i>Heliacus imperfectus</i> Sut.	..	X	..	..	..	..	X
÷ — <i>variegatus</i> Gmel.	..	..	..	..	..	..	X
<i>Hemiconus ornatus</i> (Hutt.)	..	..	..	..	..	..	X
<i>Hinnites truilli</i> Hutt.	..	..	..	..	..	..	X
<i>Lapparia hebes</i> (Hutt.)	..	X	..	..	..	..	..
<i>Latirus acuticingulatus</i> Sut.	..	..	..	..	..	X	X
— <i>brevirostris</i> (Hutt.)	..	..	..	..	..	..	X
— <i>compactus</i> Sut.	..	..	..	..	..	..	X
— <i>elatior</i> Sut.	..	X	..	..	..	..	X
— n. sp.	..	..	..	..	..	..	X
÷ <i>Leda bellula</i> A. Ad.	..	..	..	..	..	X	X
— <i>semiteres</i> Hutt.	..	X	..	..	..	X	X
÷ <i>Leptothyra fluctuata</i> (Hutt.)	..	..	..	..	..	..	X
<i>Leucosyrinx alta</i> (Harris)	..	..	..	..	..	X	X
— <i>alta transenna</i> (Sut.)	..	..	..	..	..	X	X
÷ <i>Lima angulata</i> Sow.	..	..	X	X	..	..	..
÷ — <i>bullata</i> (Born)	..	..	X	X	..	X	X
— <i>colorata</i> Hutt.	..	X	X	..	X	X	X
— <i>huttoni</i> Sut.	..	..	..	X	X	..	X
— <i>jeffreysiana</i> Tate	..	..	X	..	..	..	..
— <i>lavigata</i> Hutt.	..	..	..	..	X	X	..
÷ — <i>lima</i> (L.)	..	..	..	X	..	..	..
— <i>paleata</i> Hutt.	..	..	X	X	X	X	..
÷ — <i>suteri</i> Dall	..	..	..	..	..	X	..
÷ <i>Limopsis aurita</i> (Brocchi)	..	X	X	..	..	X	X
— <i>catenata</i> Sut.	..	X	..	X	..	X	X
— <i>zitteli</i> von Iher.	..	..	..	..	X	X	X
<i>Lissospira exigua</i> Sut.	..	..	..	..	..	..	X
<i>Lithophaga nelsoniana</i> Sut.	..	X	..	..	..	..	..
÷ <i>Loripes concinna</i> Hutt.	..	..	..	..	..	X	X
— <i>laminata</i> Hutt.	..	..	..	..	..	X	X
<i>Lyria</i> n. sp. (new to N.Z. fauna)	..	X	..	..	..	..	..
<i>Macrocallista assimilis</i> (Hutt.)	..	..	..	..	..	X	X
÷ — <i>multistriata</i> (Sow.)	..	..	..	..	..	X	X
— <i>pareoraensis</i> Sut.	..	..	..	..	..	..	X
<i>Mactra attenuata</i> Hutt.	..	..	X	..	X	..	..
— <i>chrydæa</i> Sut.	..	..	..	..	..	..	X
÷ <i>Malletia australis</i> (Q. & G.)	..	..	..	..	..	X	X
<i>Mangilia canaliculata</i> Sut.	..	..	..	..	..	X	X
÷ — <i>dictyota</i> (Hutt.)	..	..	..	..	..	..	X
— <i>gracilenta</i> Sut.	..	..	..	..	..	..	X
— <i>leptosoma</i> (Hutt.)	..	..	..	..	..	..	X
— <i>præcophinodes</i> Sut.	..	..	..	..	..	..	X
÷ — <i>protensa</i> (Hutt.)	..	..	..	..	..	..	X
÷ — <i>sinclairi</i> (Smith)	..	..	..	..	..	..	X
— <i>tenuilirata</i> Sut.	..	..	..	..	..	X	X

Alphabetical List of Genera and Species in Oamaruan—continued.

Genus and Species.	Ngaparan (Lignitic) Stage.	Waiarekan Stage.		Ototaran Stage.	Hutchin- sonian Stage.		Awamoan Stage.
		Lower or Bortonian.	Upper.		Lower.	Upper.	
<i>Mangilia</i> n. sp.	..	..	..	..	..	X	..
<i>Marginella conica</i> Harris	..	..	..	..	..	..	X
— <i>fraudulenta</i> Sut.	..	..	..	..	..	..	X
— <i>harrisi</i> Cossm.	..	..	..	..	..	X	X
÷ — <i>pygmaea</i> Sow.	..	..	..	..	..	..	X
— n. sp.	..	..	..	..	..	..	X
÷ <i>Megalatractus maximus</i> (Tryon)	..	..	..	..	..	..	X
<i>Melina zealandica</i> Sut.	..	..	..	..	..	..	..
<i>Merica</i> n. spp. (3)	..	..	..	..	..	..	X
— (<i>Aphera</i>) n. spp. (2)	..	..	..	..	..	..	X
<i>Mesalia striolata</i> Hutt.	..	..	..	..	..	..	X
— n. sp.	..	..	..	..	..	..	X
÷ <i>Mesodcsma australe</i> (Gmel.)	..	..	..	..	..	..	..
÷ — <i>subtriangulatum</i> (Gray)	..	..	..	..	..	..	..
<i>Mitra armorica</i> Sut.	..	..	..	..	..	..	X
— n. sp.	..	..	..	..	..	..	X
— n. sp.	..	..	..	..	..	X	..
<i>Modiolaria elongata</i> (Hutt.)	..	..	..	..	..	..	X
÷ <i>Modiolus australis</i> (Gray)	..	..	..	..	..	X	X
÷ <i>Monodonta coracina</i> Trosch.	..	..	..	..	..	X	X
÷ <i>Murex angasi</i> (Crosse)	..	..	..	..	..	..	X
÷ — <i>octogonus</i> Q. & G.	..	..	..	..	..	..	X
÷ — <i>zealandicus</i> Q. & G.	..	..	..	..	..	X	..
÷ <i>Myodora crassa</i> Stutchb. (new as fossil)	..	..	..	..	..	..	X
÷ — <i>pandoriformis</i> Stutchb. (new as fossil)	..	..	..	..	..	..	X
÷ — <i>subrostrata</i> Smith	..	..	..	..	..	..	X
÷ <i>Mytilus magellanicus</i> Lamk.	..	..	..	..	..	..	..
— <i>huttoni</i> Cossm.	..	..	..	..	..	X	X
÷ <i>Natica australis</i> (Hutt.)	..	..	..	..	..	..	X
÷ — <i>zealandica</i> Q. & G.	..	..	..	..	..	X	X
<i>Niso</i> n. sp.	..	..	..	..	..	X	..
÷ <i>Nucula hartvigiana</i> Pfr.	..	..	..	..	..	..	X
÷ — <i>nitidula</i> A. Ad.	..	..	..	..	..	..	X
— <i>sagittata</i> Sut.	..	..	..	..	..	X	X
÷ — <i>strangei</i> A. Ad.	..	..	..	..	..	..	..
÷ <i>Odostomia pudica</i> Sut.	..	..	..	..	..	..	X
÷ — <i>rugata</i> Hutt.	..	..	..	..	..	..	X
— n. spp. (2)	..	..	..	..	..	..	X
÷ <i>Ostrea angasi</i> Sow.	..	..	..	..	..	..	X
÷ — <i>corrugata</i> Hutt.	..	..	..	..	..	..	..
— <i>incurva</i> Hutt.	..	..	..	..	..	..	..
— <i>nelsoniana</i> Zitt.	..	..	..	..	..	X	X
÷ — <i>tatei</i> Sut.	..	..	..	..	..	X	..
— <i>wuellerstorfi</i> Zitt.	..	..	..	..	..	X	X
<i>Panope orbita</i> Hutt.	..	..	..	..	..	X	X
— <i>worthingtoni</i> Hutt.	..	..	..	..	..	X	X
÷ — <i>zealandica</i> Q. & G.	..	..	..	..	..	..	X
<i>Parvisipho</i> n. sp.	..	..	..	..	..	..	..
<i>Paphia curta</i> (Hutt.)	..	..	..	..	..	..	X
<i>Pecten accrementus</i> Hutt.	..	..	..	..	..	..	..
— <i>aldingensis</i> Tate	..	..	..	..	..	..	..
— <i>beelhami</i> Hutt.	..	..	..	..	..	X	..

Alphabetical List of Genera and Species in Oamaruan—continued.

Genus and Species.	Ngaparan (Lignite) Stage.	Waiarekan Stage.		Ototaran Stage.	Hutchinsonian Stage.		Awamooan Stage.
		Lower or Bortonian.	Upper.		Lower.	Upper.	
<i>Pecten beethami</i> var. B. Hutt.	..	..	..	X	..	..	..
— <i>burnetti</i> Zitt.	..	..	..	X	X	X	..
— <i>chathamensis</i> Hutt.	..	..	..	X	..	X	..
— <i>delicatulus</i> Hutt.	..	..	..	X	X	..	..
— <i>fischeri</i> Zitt. . .	..	..	..	..	..	..	X
— <i>hochstetteri</i> Zitt.	..	..	..	..	..	..	X
— <i>hutchinsoni</i> Hutt.	..	..	..	X	X	X	X
— <i>huttoni</i> (Park)	..	..	..	X	X	X	X
— <i>marshalli</i> Sut.	..	..	..	X	..	..	..
— <i>polymorphoides</i> Zitt.	..	..	..	X	..	..	..
÷ — <i>radiatus</i> Hutt.	..	..	..	..	X	X	X
— <i>scandula</i> Hutt.	..	..	..	..	..	..	X
— <i>semiplicatus</i> Hutt.	..	..	..	X	X	X	X
— <i>triphooki</i> Zitt.	..	..	..	X	X	..	..
— <i>venosus</i> Hutt.	..	..	..	X	..	..	..
— <i>williamsoni</i> Zitt.	..	..	..	..	X	X	..
— <i>yakliensis</i> Ten.-Woods.	..	..	..	X	X	X	X
÷ — <i>zelandiæ</i> Gray	..	..	..	..	..	X	X
— n. sp.	..	..	..	X	..	..	..
÷ <i>Phalium achatinum pyrum</i> (Lamk.)	..	..	..	..	..	..	X
<i>Pholadidea thomsoni</i> Sut.	..	..	..	X	..	..	..
<i>Pholadomya neozelandica</i> Hutt.	..	..	..	X	..	..	..
<i>Phos cingulatus</i> (Hutt.)	..	..	..	..	..	..	X
<i>Placunanomia incisura</i> Hutt.	..	..	..	X	..	X	X
÷ — <i>zelandica</i> (Gray)	..	..	..	X	..	X	X
<i>Pleurotomaria tertiaria</i> McCoy	..	..	..	X	..	..	..
÷ <i>Polinices amphialus</i> (Watson)	..	..	..	..	..	..	X
— <i>gibbosus</i> (Hutt.)	..	..	..	X	X	X	X
— <i>huttoni</i> von Iher.	..	..	..	X	X	X	..
— <i>lævis</i> (Hutt.)..	..	..	..	..	..	..	X
— <i>ovatus</i> (Hutt.)	..	..	..	X	X	..	X
÷ <i>Poroleda lanceolata</i> (Hutt.)	..	..	..	X	..	..	..
÷ <i>Protocardia pulchella</i> (Gray)	..	..	..	X	X	..	X
— <i>sera</i> Hutt. . .	..	..	..	X	X	..	X
÷ <i>Psammobia lineolata</i> Gray	..	..	..	X	X	X	X
÷ — <i>stangeri</i> Gray	..	..	..	..	..	..	X
÷ <i>Pupa alba</i> (Hutt.)	..	..	..	X	..	..	..
<i>Rapana neozelandica</i> Sut.	..	..	..	X	..	..	..
<i>Ringicula uniplicata</i> Hutt.	..	..	..	..	..	..	X
÷ <i>Rissoina emarginata</i> (Hutt.)	..	..	..	..	..	..	X
— n. sp.	..	..	..	..	..	..	X
÷ <i>Sarepta obolella</i> (Tate)	..	..	..	..	..	..	X
<i>Scaphella elegantissima</i> Sut.	..	..	..	X	..	..	..
÷ <i>Schismope atkinsoni</i> (Ten.-Woods)	..	..	..	..	..	..	X
÷ <i>Seila bulbosa</i> Sut. . .	..	..	..	..	..	..	X
÷ <i>Serpulorbis sipho</i> (Lamk.)	..	..	..	X	..	..	X
÷ <i>Siliquaria weldii</i> Ten.-Woods (new as a fossil)	..	..	..	..	..	X	..
<i>Sinum carinatum</i> (Hutt.)	..	..	..	..	..	..	X
— <i>cinctum</i> (Hutt.)	..	..	..	..	..	X	X
— <i>elegans</i> Sut. . .	..	..	..	X	..	..	..
÷ <i>Siphonalia caudata</i> (Q. & G.)	..	..	..	..	..	X	X
— <i>conoidea</i> (Zitt.)	..	..	..	X	..	X	X

Alphabetical List of Genera and Species in Oamaruan—continued.

Genus and Species.	Ngaparan (Lignite) Stage.	Waiarekan Stage.		Otago Stage.	Hutchinsonian Stage.		Awamoo Stage.
		Lower or Bortonian.	Upper.		Lower.	Upper.	
<i>Siphonalia costata</i> (Hutt.)				X			X
÷ <i>dilatata</i> (Q. & G.)					X		X
— <i>excelsa</i> Sut.						X	X
÷ <i>mandarina</i> (Duclos)		X					X
÷ <i>nodosa</i> (Mart.)		X		X		X	X
— <i>nodosa zitteli</i> Sut.							X
— <i>subnodosa</i> (Hutt.)		X				X	
— <i>turrita</i> Sut.			X	X			X
— n. sp.				X			
— n. sp.							X
÷ <i>Siphonium planatum</i> Sut.			X	X	X	X	X
<i>Solariella stoliczkae</i> (Zitt.)							X
— <i>sulcatina</i> Sut.		X					
÷ <i>Spisula ordinaria</i> (Smith)		X					
<i>Streptochetus</i> n. sp. (genus new to N.Z. fauna)							X
— n. sp.		X					
<i>Struthiolaria cincta</i> Hutt.						X	X
— <i>frazieri</i> Hutt.							X
— <i>tuberculata</i> Hutt.					X		X
— <i>tuberculata concinna</i> Sut.		X					
÷ <i>vermis</i> (Mart.)						X	
<i>Submarginula elata</i> Sut.						X	
÷ <i>intermedia</i> (Reeve)							X
<i>Surcula fusiformis</i> (Hutt.)		X		X		X	X
— <i>hamiltoni</i> (Hutt.)						X	
— <i>huttoni</i> Sut.							X
— <i>oamarutica</i> Sut.							X
— <i>pareoraensis</i> (Sut.)							X
— <i>serotina</i> Sut.		X					
— n. sp.		X					
— n. spp. (2)						X	
— n. sp.							X
<i>Sveltia</i> n. sp.							X
÷ <i>Tellina glabrella</i> Desh.						X	X
<i>Terebra costata</i> Hutt.							X
— <i>orycta</i> Sut.						X	X
÷ <i>tristis</i> Desh.							X
<i>Teredo heaphyi</i> Zitt.		X	X	X	X	X	X
<i>Tornatina</i> n. sp.							X
÷ <i>Trichotropis clathrata</i> Sow.						X	
÷ <i>Triphora lutea</i> Sut.							X
÷ <i>Trivia avellanoides</i> (McCoy)							X
÷ <i>Trochus clathamensis</i> (Hutt.)							X
÷ <i>tiaratus</i> Q. & G.							X
— n. sp.			X				
— n. sp.				X			
÷ <i>Trophon hanleyi</i> (Angas)							X
— <i>lepidus</i> Sut.							X
— <i>minutissimus</i> Sut.							X
— n. sp.			X				
<i>Turbo marshalli</i> Thomson				X			
— <i>superbus</i> Zitt.			X				

Alphabetical List of Genera and Species in Oamaruan—continued.

Genus and Species.	Ngaparan (Lignite) Stage.	Waiarekan Stage.		Otolaran Stage.	Hutchinsonian Stage.		Awamoan Stage.
		Lower or Bortonian.	Upper.		Lower.	Upper.	
<i>Turbonilla oamarutica</i> Sut.	..	..	..	..	..	X	X
— <i>prisca</i> Sut.	..	..	..	..	..	..	X
÷ — <i>zealandica</i> (Hutt.)	..	..	..	..	..	X	X
<i>Turris regius</i> Sut.	..	..	..	..	..	..	X
— <i>utleyi</i> Sut.	..	..	..	..	..	X	..
<i>Turritella ambulacrum</i> Sow.	..	..	..	..	..	X	..
÷ — <i>carlottæ</i> Wats.	..	..	..	X	..	X	X
— <i>cavershamensis</i> Harris	..	..	..	X	X	..	X
— <i>concava</i> Hutt.	..	..	..	X	..	X	X
÷ — <i>pagoda</i> Reeve	..	..	..	..	..	X	..
— <i>patagonica</i> Sow.	..	..	..	..	..	..	X
÷ — <i>rosea</i> Q. & G.	..	..	..	..	..	..	X
— <i>semiconcava</i> Sut.	..	..	..	X	..	X	X
÷ — <i>symmetrica</i> Hutt.	..	..	..	X	..	X	X
— n. sp.	..	..	..	..	..	..	X
<i>Typhis maccoyi</i> Ten.-Woods	..	..	..	..	..	X	X
<i>Venericardia acanthodes</i> Sut.	..	..	..	..	..	..	..
÷ — <i>difficilis</i> (Desh.)	..	..	..	X	X	X	X
— <i>difficilis benhami</i> (Thomson)	..	..	..	..	X	..	..
— cf. <i>inæqualis</i> Phil.	..	..	..	..	..	..	X
÷ — <i>lutea</i> (Hutt.)	..	..	..	..	..	X	X
— <i>purpurata</i> (Desh.)	..	..	..	..	X	X	X
— <i>pseutes</i> Sut.	..	..	..	X	..	X	X
— <i>subintermedia</i> Sut.	..	..	..	..	..	..	X
<i>Vexillum apicale</i> (Hutt.)	..	..	..	..	..	..	X
— <i>enysi</i> (Hutt.)	..	..	..	..	..	..	X
— <i>linctum</i> (Hutt.)	..	..	..	..	..	..	X
÷ — <i>marginatum</i> (Hutt.)	..	..	..	..	..	..	X
— <i>rutidolomum</i> Sut.	..	..	..	..	..	..	X
÷ <i>Volvulella reflexa</i> (Hutt.)	..	..	..	..	..	..	X
÷ <i>Xenophora corrugata</i> (Reeve)	..	..	..	..	X	..	..
— sp.	..	..	..	..	..	X	..
÷ <i>Zenatia acinaces</i> (Q. & G.)	..	..	..	X	..	X	X

Bortonian Molluscs.

Of the sixty-four species in the Bortonian beds eighteen have not been found as fossils above that horizon. These are,—

Athleta necopinata Sut.
Clio rangiana (Tate).
Euthriofusus spinosus Sut.
Galeodes n. sp.
Lapparia hebes Hutt.
Lithophaga nelsoniana Sut.
Lyria n. sp.
÷ *Nucula strangeri* A. Ad.
Parvisipho n. sp.

÷ *Poroleda lanceolata* Hutt.
Rapana neo-zealanica Sut.
Sinum elegans Sut.
Solariella sulcatina Sut.
÷ *Spisula ordinaria* (Smith).
Streptochetus n. sp.
Struthiolaria tuberculata concinna Sut.
Surcula n. sp.
Surcula serotina Sut.

Of these, *Nucula strangei*, *Spisula ordinaria*, and *Poroleda lanceolata* reappear in Recent times. *Cardium huttoni* von Iher, is confined to the Lower and Upper Waiarekan; while *Pholadomya neo-zealanica* Hutt. ranges up to the middle of the Ototaran.

The genera *Lyria* and *Streptochetus* are new to the New Zealand fauna.

Upper Waiarekan Molluscs.

Of the sixty-four species recorded from this stage, sixteen are confined to this horizon, namely,—

<i>Amusium zitteli</i> (Hutt.).	<i>Lima jeffreysiana</i> Tate.
<i>Calliostoma</i> n. sp.	÷ <i>Mesodesma australe</i> (Gmel.).
÷ <i>Cardita calyculata</i> (L.).	÷ <i>Mytilus magellanicus</i> Lamk.
<i>Cardium</i> n. spp. (2.)	<i>Pecten</i> n. sp.
<i>Clio annulata</i> (Tate).	÷ <i>Pupa alba</i> (Hutt.).
<i>Cuspidaria</i> n. sp.	<i>Trochus</i> n. sp.
<i>Dentalium</i> n. sp.	<i>Turbo superbus</i> Zitt.
÷ <i>Dosinia cærulea</i> Reeve.	

Five of the above species are Recent, but have not been seen in the Ototaran, Hutchinsonian, or Awamoan horizons.

Astræa heliotropium Mart., a Recent species, runs into the Ototaran and disappears; while *Crassatellites obesus* A. Ad., a living form which first appears in the Upper Waiarekan, runs through all the horizons. *Pecten polymorphoides* Zitt. was found only in the Upper Waiarekan and Ototaran.

Ototaran Molluscs.

Of the ninety-five species from the Ototaran, no less than twenty-seven are apparently restricted to that division of the Oamaruan. They are,—

÷ <i>Anomia huttoni</i> Sut.	<i>Ostrea incurva</i> Hutt.
<i>Aturia australis</i> McCoy.	<i>Pecten accrementus</i> Hutt.
<i>Cardium</i> n. sp.	<i>Pecten beethami</i> var. B. Hutt.
<i>Clavagella</i> n. sp.	<i>Pecten chathamensis</i> Hutt.
<i>Columbraria</i> n. sp.	<i>Pecten venosus</i> Hutt.
<i>Cypræa ovulata</i> Tate.	<i>Pholadidea thomsoni</i> Sut.
<i>Epitonium nympha</i> (Hutt.).	<i>Pleurotomaria tertiaria</i> McCoy.
<i>Epitonium</i> n. sp.	<i>Scaphella elegantissima</i> Sut.
<i>Euthria media</i> (Hutt.).	<i>Siphonalia</i> n. sp.
<i>Ficus transennus</i> Sut.	<i>Trochus</i> n. sp.
<i>Fusinus</i> n. sp.	<i>Turbo marshalli</i> Thomson.
÷ <i>Gadinia conica</i> Angas.	<i>Venericardia acanthoides</i> Sut.
÷ <i>Lima lima</i> (L.).	<i>Venericardia difficilis benhami</i> (Thomson).
÷ <i>Mesodesma subtriangulatum</i> (Gray).	

Cymbiola corrugata (Hutt.) makes its first appearance, and runs through all the later members of the system. The list includes four living species, none of which reappear in the Hutchinsonian or the Awamoan. The genera *Clavagella* and *Columbraria* are new to the New Zealand fauna.

Almost all the molluscs from the Ototaran were obtained from the fossiliferous tuffs intercalated in the Oamaru stone. The Oamaru stone, being the remains of a polyzoan reef, contains only a few molluscs, those mostly *Epitonium* and various pectens, none of which are Recent.

The molluscs contained in the Kakanui tuffs represent the contemporary molluscan fauna of the adjacent seas. Most of the fossils occur in the upper portion of the tuffs. It

is probable that the migration of the molluscs to this area only began when the explosive outbursts became feeble in the waning stage of the Ototaran period of volcanic activity. When complete quietude once more reigned the polyzoans again took possession of this area, and soon buried the molluscan invaders under a thick sheet of limestone.

Pyroclastic deposits, from the nature of their origin, usually accumulate rapidly. During the Tarawera eruption in 1886 a sheet of fine and coarse volcanic ash was spread over hundreds of square miles in less than six hours, ranging from 20 ft. or more in thickness near the centre of activity to nothing some miles distant. The volcanic outbursts of the Ototaran stage were extremely violent in the Kakanui area during the earlier phases, but the activity became feeble and intermittent after the first great explosive outburst. How long the molluscan occupation of the coral-reef area lasted cannot be determined, but judging from present-day volcanic phenomena the view may be safely advanced that the time was relatively short.

Many species that appear in the Waiarekan are absent from the Ototaran, but reappear in the overlying Hutchinsonian or Awamoan. The character of the Mollusca would doubtless be mainly dependent on the depth and condition of the sea-floor and the food-supply.

Hutchinsonian Molluscs.

Of the fifty-four species identified from the Lower Hutchinsonian, four have so far been found only in that horizon. They are,—

Cypræa trelissickensis Sut.

Fusinus solidus Sut.

Epitonium n. sp.

Xenophora corrugata Reeve.

The living species, *Xenophora corrugata* Reeve, makes its appearance here, but is absent in the overlying beds.

Among the molluscs that reach their upward limit in the Lower Hutchinsonian are,—

Pecten delicatulus Hutt.

Polinices huttoni von Iher.

Pecten triphooki Zitt.

The material composing the Lower Hutchinsonian is highly glauconitic sands, usually calcareous and abounding in brachiopods, pectens, Foraminifera, corals, and polyzoans. The conditions of deposition, as indicated by the contained fauna, were clear deep waters that did not favour the intrusion of the varied molluscan life that frequents a muddy or sandy sea littoral. Hence many of the species of molluscs present in the Waiarekan and Ototaran tuffs are absent from the Lower Hutchinsonian, but reappear in the Upper Hutchinsonian and Awamoan.

Of 142 species from the Upper Hutchinsonian not less than 106 pass upward into the Awamoan; of the remainder, twenty-four appear to be confined to this horizon, namely,—

÷ *Admete præcursoria* Sut.

Mitra n. sp.

Ancilla mucronata (Sow.).

÷ *Murex zelandicus* Q. & G.

Anomia trigonopsis Hutt.

Niso n. sp.

Astarte australis Hutt.

÷ *Ostrea tatei* Sut.

Borsonia cincta (Hutt.).

÷ *Struthiolaria vermis* (Mart.).

÷ *Calliostoma pellucidum* (Val.).

Submarginula elata Sut.

Cominella exsculpta Sut.

Surcula hamiltoni (Hutt.).

Cytherea n. sp.

Surcula n. spp. (2).

Epitonium n. sp.

÷ *Trichotropis clathrata* Sow.

Exilia dalli Sut.

Turris utleyi Sut.

÷ *Lima suteri* Dall.

÷ *Turritella pagoda* Reeve.

Mangilia n. sp.

Seven of the species in the above list reappear in the living molluscan fauna, but have not been identified in the Awamoan.

The Upper Hutchinsonian appears to be the upward limit of *Pecten burnetti* Zitt. and *P. williamsoni* Zitt.

Although this horizon underlies the Awamoan, it contains a higher percentage of living species than the Awamoan. This has probably arisen from some change in the conditions of deposition before the beginning of the Awamoan. This change, though indicated by the absence from the Awamoan of several Recent species that are common in the Upper Hutchinsonian, could not have been of great moment, as nearly 75 per cent. of the molluscs found in the latter stage pass upwards into the Awamoan.

Awamoan Molluscs.

Of the 293 species from this stage, 161 species (or 55 per cent.) appear for the first time. Of these, *Seila bulbosa* Sut., *Triphora lutea* Sut., *Siliquaria weldii* Ten.-Woods, and *Helicaculus variegatus* (Gmel.) are new as fossils; while *Rissoina emarginata* (Hutt.), *Odostomia pudica* Sut., *Eulima obliqua* (Hutt.), *Anachis pisanioiopsis* (Hutt.), and *Mangilia dictyota* (Hutt.) are new to the Miocene. *Trivia arellanoides* (McCoy) is new to the New Zealand fauna.

OAMARUIAN BRACHIOPODS.

Tabulation of Oamaruan Brachiopods.

Genus and Species.	Ngaparan Stage.	Waiarekan Stage.		Ototaran Stage.	Hutchinsonian Stage.		Awamoan Stage.
		Lower.	Upper.		Lower.	Upper.	
<i>Liothyrella oamarutica</i> (Boehm)	..	..	..	X	..	..	..
— <i>boehmi</i> Thomson	..	..	..	X	X	..	..
— <i>londonensis</i> Thomson	..	..	..	X	X	..	..
— <i>pulchra</i> Thomson	..	..	..	X	..	..	..
— <i>concentrica</i> (Hutt.)	..	..	..	X	..	..	..
<i>Terebratulina oamarutica</i> Boehm	..	..	X	X	X	..	..
— <i>suessi</i> Hutt.	..	..	X	X	X	..	..
<i>Murravia catinuliformis</i> (Tate)	..	..	..	..	X	..	..
<i>Terebratella totaraensis</i> Thomson	..	..	..	X	..	..	..
— <i>kakanuiensis</i> Hutt.	..	..	..	X	..	..	..
— sp., cf. <i>neozelandica</i> von Iher.	..	..	..	X	..	..	..
<i>Pachymagas parki</i> (Hutt.)	..	..	..	X	X	X	X*
— <i>ellipticus</i> Thomson	..	..	..	X	X	..	..
— <i>trellissickensis</i> Thomson	..	..	..	..	X	..	..
— <i>huttoni</i> Thomson	..	..	..	..	X	..	..
<i>Rhizothyris rhizoida</i> (Hutt.)	..	..	..	X	X	..	..
<i>Neothyris tapirina</i> (Hutt.)	..	..	X	X	X	..	..
— <i>utleyi</i> Thomson (MS.)	..	..	..	X	..	..	..
— <i>esdailei</i> Thomson	..	..	X	..	..	..	..
<i>Magella carinata</i> Thomson	..	..	..	X	..	..	..
<i>Etheia gaulteri</i> (Morris)	..	..	X	X	X	..	..
<i>Hemithyris squamosa</i> (Hutt.)	..	..	..	X	..	..	..
— <i>nigricans</i> (Sow.)	..	..	..	..	..	X	X
— <i>depressa</i> Thomson	..	..	..	X	X	..	..
— <i>sublaevis</i> Thomson	..	..	..	X	..	..	..

* Apparently derived from underlying Upper Hutchinsonian.

Of the twenty-five species of brachiopods listed above as found in the Oamaruan, twenty species are found in the Ototaran, and, of these, one-half pass upward into the Lower Hutchinsonian. Four of the twenty first appear in the upper portion of the Upper Waiarekan, and only one of them (*Pachymagas parki* (Hutt.)) reaches the Upper Hutchinsonian. In other words, the brachiopods are almost exclusively confined to the calcareous members of the system.

Most of the brachiopods are very limited in horizontal distribution. Thus *Terebratula oamarutica*, *T. boehmi*, and *Terebratulina oamarutica* are restricted to the coastal area bounded approximately on the west by the Dunedin-Oamaru Railway; and *Terebratula pulchra*, *T. landonensis*, *Terebratella totaraensis*, and *Neothyris uttleji* to the area lying west of the railway. On the other hand, *Terebratulina suessi*, *Ætheia gaulteri*, *Neothyris tapirina*, *Pachymagas parki*, *Rhizothyris rhizoida*, and *Hemithyris squamosa* are distributed throughout the whole of north-east Otago. *Pachymagas parki* occurs in great abundance in the Lower Hutchinsonian, usually to the exclusion of all other brachiopods except *Rhizothyris rhizoida*, which is nearly always present with it.

Dr. Thomson states (*in litteris*, November, 1916) that the following manuscript species of his occur in the Oamaru district in addition to those listed above: *Hemithyris antipoda*, *Bouchardia minima*, *Argyrotheca* or *Kraussina* or *Megerlina* sp., *Pachymagas abnormis*, and *Neothyris esdailei*. *Terebratella totaraensis* Thomson is possibly the same as *T. kakanuiensis* Hutt. *Pachymagas marshalli* Andrew he considers a synonym of *P. parki* Hutt. (See also pages 117-119.)

GENERAL CONCLUSIONS.

The adoption of stage-names as representing time-planes has been fully justified by the paleontological evidence. An obvious advantage of stage-names is that it avoids a source of error that is apt to arise through the adoption of a lithological name, or of a place-name that has become intimately associated with a particular type of rock. The use in previous reports of the name "Oamaru stone" as a time-name has sometimes led to the erroneous conclusion that all the rocks of this age throughout New Zealand must be limestone, or in some way form lines of escarpment like the Oamaru stone of the Oamaru district.

The analysis of the lists of fossils shows that the proportion of Recent species in the Oamaruan ranges from 23 per cent. in the Lower Waiarekan to 33.3 per cent. in the Awamoan, a result which clearly establishes the Miocene age of the Oamaruan.

Thin flaggy fossiliferous layers of the Bortonian of Lower Waiarekan age represent the first encroachment of the sea on the Ngaparan lignitic series. The Bortonian contains a molluscan fauna with some features that easily distinguish it from the Upper Waiarekan fauna. The Upper Waiarekan fauna shows a closer relationship to the Ototaran than the Bortonian, which in some respects stands apart.

As the advancing sea came from the east or south-east, it is probable that the Bortonian will not be present at Wharekuri or in the Waihao district of South Canterbury. In this case the marine beds overlying the lignitic measures at these places would find their nearest time-equivalent in the Upper Waiarekan.

The Oamaru stone was formed from the remains of Polyzoa. It is local in distribution, and covers only a portion of the Oamaru district. Between Kakanui and Oamaru it is partly replaced by intercalated fossiliferous tuffs and breccias. To the north-west it rapidly thins, and finally disappears in the lower Waitaki Valley, its place being taken by sandy beds.

The Lower Hutchinsonian is the most distinctive and persistent horizon of the Oamaruan system; it always overlies the Oamaru stone. In the Oamaru area it consists of calcareous glauconitic greensands that at Landon Creek and lower Waitaki

Valley are partly or wholly replaced by calcareous glauconitic sandstone. But whether greensands or glauconitic sandstone, the characteristic brachiopod *Pachymagas parki* Hutt. and the peculiar corals *Isis dactyla* Ten.-Woods and *Mopsea hamiltoni* (Thomson) are always present. The Waitaki stone is underlain by the greensands.

The results of the present survey confirm the view of Captain Hutton, Sir James Hector, and Alexander McKay that the Waitaki stone is Hutchinsonian (pp. 65 and 66) as opposed to the contention of Thomson, Uttley, and others that the Waitaki stone is the horizontal equivalent of the Oamaru stone.

At Waihao in South Canterbury the Waihao stone, a calcareous glauconitic sandstone, is underlain by greensands and followed conformably, as shown by McKay and Thomson, by the Awamoan Mount Harris beds. Investigation will probably show that the Waihao stone is also Hutchinsonian. The view that the Waihao stone is the time-equivalent of the Oamaru stone (= Ototaran) would imply the absence of the whole of the Hutchinsonian in South Canterbury. Such a hiatus would mean an unconformity between the Waihao stone and the Mount Harris beds, of which, however, there is no evidence.

CORRELATION OF OAMARU, WAITAKI, AND WAIHAO CAINOZOIC STRATA.

		<i>Oamaru District.</i>	<i>Lower Waitaki Valley.</i>	<i>Waihao District.</i>
Awamoan	..	Blue clays and shelly sands	Sandy beds	Blue clays and sands, calcareous.
Upper Hutchinsonian	..	Glauconitic sandstone (Devil's Bridge, Landon Creek)	Calcareous glauconitic sandstone (Waitaki stone)	Glauconitic sandstone (Waihao stone).
Lower Hutchinsonian	..	Greensands	Greensands	Greensands.
Ototaran	..	Coralline (Oamaru) limestone	Bluish-grey glauconitic sandy beds	Bluish-grey sandy beds.
Waiarekan	..	Sandy clays and sandstones	Sandy beds and sandstones	Sandy clays and sandstones.
Ngaparan	..	Quartzose sands, &c., with lignite	Quartzose sands, &c., with lignite	Quartzose sands, &c., with lignite.

The Oamaruan is the most widespread Tertiary formation in New Zealand. At one time it formed a continuous marginal sheet around the shores of Miocene New Zealand; and even now it exists as isolated remnants on the coasts of both Islands. It occurs at sea-level, usually as gently sloping strata; and also far inland, either as horizontal strata lying on faulted blocks as on the west coast of Nelson, or as wedges deeply involved in orogenic folds as in the Lake Wakatipu area, or as down-faulted blocks as in the Trelissick Basin. The valuable coal-seams it contains make it of great economic importance. Beyond the limits of New Zealand the Oamaruan is well represented at the Chatham and Campbell Islands.

In age the Oamaruan may be correlated with the Table Cape beds of Tasmania, the Janjukian of Southern Australia, the Navidad beds of Chile, and perhaps with the Middle Cainozoic deposits of Patagonia.

CHAPTER X.

OLDER PLEISTOCENE DEPOSITS.

HIGH-LEVEL GRAVELS.

THESE gravels cover the Oamaru tableland to a depth ranging from 2 ft. to 60 ft. They consist mainly of well water-worn greywacke boulders and pebbles, together with a small proportion of pebbles of quartz and red jasperoid rock. The source of the material is to be found in the Kakanui Mountains and upper Waitaki Valley. The gravels were laid down by the Waitaki River when the land stood some 200 ft. or more lower than at present.

The Oamaru tableland rises gradually from a height of 230 ft. at the sea-front to a height of 550 ft. at Duntroon. At the base of the gravel, as seen on the north side of Target Gully half a mile below the Oamaru Reservoir, there is a bed of fine sand some 8 ft. or 10 ft. thick.

The thin sheet of gravel in the area between Three Roads and the Awamoa Creek is largely composed of quartzose material. It appears to have been laid down by the Kakanui River during the Pleistocene.

CHAPTER XI.

NEWER PLEISTOCENE AND RECENT.

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NEWER PLEISTOCENE.

RAISED BEACHES.

42 ft. Raised Beach.

THE blasting operations of the Oamaru Harbour Board have destroyed the greater portion of this beach. A small portion of it still remains on the quarry-face at the end of the outer breakwater, not far from the steps leading up to the lighthouse (Fig. 32, page 75). The rock in which it was cut is the tachylitic breccia at one time used by the Harbour Board for harbour-improvement works.

The raised beach consists of greywacke pebbles mixed with sand and broken shells. The molluscs identified by Suter from this raised rock-platform were,—

Mytilus edulis L.

Limopsis aurita (Brocchi).

Mytilus sp.

Halotis australis Gmel.

Ostrea angasi Sow.

A small remnant of this platform still remains at Boatman's Harbour, but elsewhere it is obscured by silts and slope deposits. All the molluscs on this raised platform are Recent.

12 ft. Raised Beach.

This forms a narrow rock-ledge fringing the coast at many places between the Oamaru Breakwater and the Rifle Butts. It is also well seen at Kakanui and All Day Bay.

At the breakwater it is excavated in the tachylitic breccia; at Boatman's Harbour, in the basaltic pillow-lava; at Cape Wanbrow, in tuffs; at the Rifle Butts, in the different members of the marine Oamaruan strata; at Kakanui, in limestone and in tuffs. This rock-platform has everywhere suffered greatly from the effects of marine erosion, and in most places has been worn back till it is now a narrow ledge varying from a few inches to a few yards wide.

The raised beach resting on this platform of marine erosion consists of pebbly gravel and gritty sand mixed with marine shells. At Cape Wanbrow and the Rifle Butts shells are very abundant. The following species, all Recent, were collected between Cape Wanbrow and the Rifle Butts:—

Helcioniscus ornatus (Dillw.).

Trochus tiaratus Q. & G.

Helcioniscus ornatus inconspicuus
(Gray).

Monodonta coracina (Troschel).

Monodonta athiops (Gmel.).

Helcioniscus radians (Gmel.).

Cantharidus tenebrosus A. Ad.

Helcioniscus radians affinis Gmel.

Calliostoma punctulatum (Mart.).

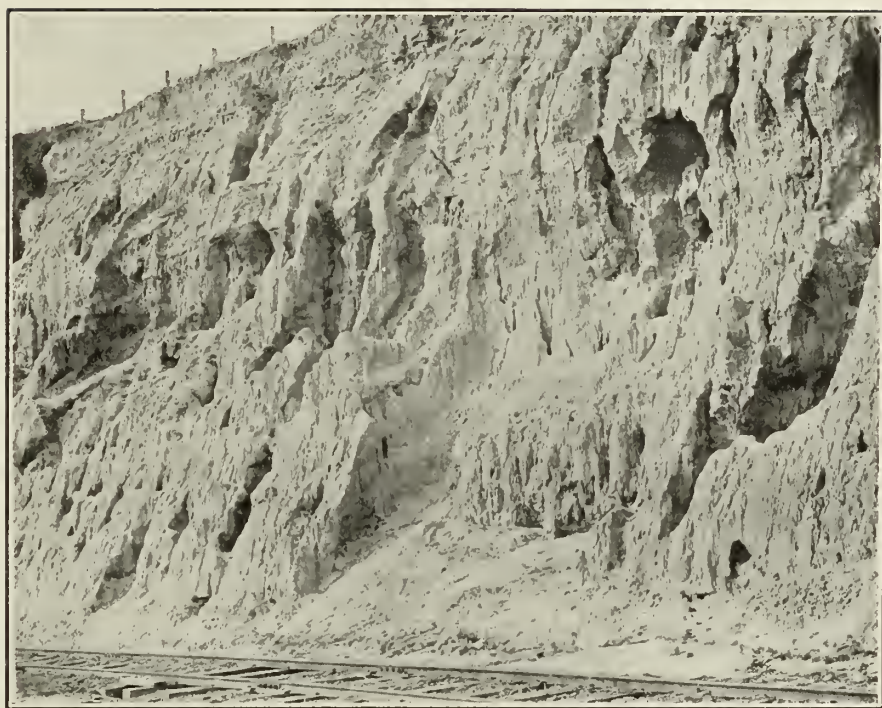
Helcioniscus radians flavus (Hutt.).

Siphonaria obliquata Sow.

Emarginula striatula Q. & G.

Turbo smaragdus (Mart.).

PLATE XII.



A. C. Gifford, photo.]

PLEISTOCENE SILTS NEAR BREAKWATER, OAMARU.

<i>Calyptraea maculata</i> (Q. & G.).	<i>Ostrea reniformis</i> Sow. (?)
<i>Trichotropis clathrata</i> Sow.	<i>Ostrea tatei</i> Sut.
<i>Argobuccinum tumidum</i> (Dkr.)	<i>Venericardia purpurata</i> (Desh.).
= <i>argus</i> of Manual.	= <i>australis</i> of Manual.
<i>Euthria striata</i> (Hutt.).	<i>Venericardia difficilis</i> (Desh.).
<i>Trophon corticatus</i> (Hutt.).	<i>Tellina alba</i> Q. & G.
<i>Trophon plebejus</i> (Hutt.).	<i>Leptomya lintea</i> (Hutt.).
<i>Fulgoraria arabica elongata</i> (Swains.).	<i>Mesodesma subtriangulatum</i> (Gray).
<i>Anomia huttoni</i> Sut.	<i>Mactra discors</i> Gray.
<i>Glycymeris modesta</i> (Angas).	<i>Spisula æquilateralis</i> (Desh.).
<i>Mytilus edulis</i> L.	<i>Dosinia anus</i> (Phil.).
<i>Mytilus canaliculus</i> Mart. (?)	<i>Cythærea oblonga</i> (Hanley) (?)
(fragments).	<i>Chione mesodesma</i> (Q. & G.).
<i>Mytilus magellanicus</i> Lamk.	<i>Terebratella sanguinea</i> Leach.
<i>Ostrea angasi</i> Sow.	

YELLOW SILTS.

The silts rest on the Pleistocene gravels on the Oamaru tableland, on the marine Oamaruian strata in the Awamoan syncline, and on the Miocene volcanic rocks between Oamaru and Deborah and around Cape Wanbrow. They are very fine and uniform in texture, and usually pale yellowish-brown in colour. The greatest depth of these silts is along the sea-front of the Oamaru tableland behind Oamaru, and between the railway and the breakwater on the lower slopes of the Cape Hill. Generally they are thickest in hollows and on the lee-side of the ridges.

Behind Oamaru, between Eden and Chamberlin streets, they are piled up to a depth of over 30 ft. against the outer slope of the hill, but as they rise upward they thin out rapidly, like drifts of wind-borne sand. Drifts of silt over 50 ft. deep lie against the foot of the hill-slopes facing the breakwater. (Plate XII.)

No fossil remains were found in the silts. At the Rifle Butts there is a slope deposit consisting of sandstone blocks and silts; in this there occur many moa-bones, mostly badly preserved. This deposit is evidently younger than the silts.

It is generally believed that the silts are dried glacial muds that were carried seaward from the Waitaki Valley by strong north-west winds during the Pleistocene extension of the glaciers. Their mode of occurrence and their wide distribution tend to show that they were wind-borne. They probably originated during the retreat of the old Waitaki and other glaciers.

RECENT.

RIVER AND VALLEY GRAVELS.

These cover the great Papakaio Plain. They form several low broad terraces, which mark a gradual elevation of the land in comparatively late times.

A wide gravel plain borders the Kakanui River from Maheno to a point a mile beyond the Kauroo River junction.

CHAPTER XII.

ECONOMIC.

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STONE FOR HARBOUR-WORKS.

THE Oamaru district has already been examined by Mr. P. G. Morgan* and Dr. Thomson† for possible quarry-sites where suitable stone could be obtained for harbour-works.

Careful examination was made of all the possible sources of supply mentioned by Morgan and Thomson, but none were found satisfactory. It is laid down by harbour engineers that a stone for harbour-improvement works in exposed places must be hard and heavy, and procurable in large blocks at a reasonable cost. When these conditions cannot be fulfilled it is considered best and most economical to use concrete blocks.

The basalts and dolerites in the district are always so much shattered that the obtaining of large blocks of them would be too costly. Thomson and Morgan suggested that an experiment should be made with Oamaru stone for the breakwater-extension works. A ledge of Oamaru stone projects from the sea-cliffs at Shirley Creek, near the Rifle Butts, and it seems to have resisted the action of the sea fairly successfully, but at this place the only abrasive material is a rather coarse sand. At the outer breakwater at Oamaru the Oamaru stone would be subject to the pounding of waves loaded with coarse gravel, and it is doubtful if such a soft rock would be able to resist the assault successfully. Limestones, no matter how hard, are always liable to be attacked by boring molluscs. The Plymouth Breakwater, erected at great cost of Portland limestone, was in time destroyed by the attack of the *Teredo*. If the Oamaru stone blocks were protected by an apron of harder rock it would make a good material for harbour-works, provided it were not attacked by the *Teredo*. In some situations limestones are not attacked by sea molluscs, hence it would be advisable to make an experiment with Oamaru stone as suggested by Thomson and Morgan.

The special requirement of the Oamaru Harbour scheme is that the stone must be procurable in 12-ton blocks, at a cost not exceeding 7s. 6d. per ton delivered at the breakwater. The only stone that fulfils this requirement occurs on the lower slopes of the hill about half a mile above Peebles. Here there is a large deposit of hard limonitic conglomerate that could be easily quarried in blocks up to 100 tons. The deposit lies close to the main road to Duntroon, and the railway could be connected with the quarry by a short siding. The cost of quarrying this stone and of loading and railway freight would amount to about 7s. per ton.

BUILDING-STONE.

Among the free-cutting limestones of New Zealand the Oamaru building-stone is without a rival. Large deposits of it occur at Deborah, Totara, Teschemaker's, Weston, Gay's, Teaneraki, and Devil's Bridge. It is proposed to deal with the Oamaru stone as a building-stone in a separate paper.

* *Ninth Annual Report (New Series), Geological Survey Branch, Appendix C, 1915, p. 96.*

† *Loc. cit.*, pp. 98-100.

LIMESTONES.

Valuable deposits of hard limestone suitable for burning for lime for agricultural purposes occur at Flat Top Hill and Teaneraki. The deposits at Kakanui, Deborah, and Hutchinson's Quarry are practically exhausted.

Average samples of limestone and calcareous sandstone were analysed by Dr. MacLaurin, with the following results:—

			<i>Analyses.</i>				
			(1.)	(2.)	(3.)	(4.)	(5.)
Insoluble in acid	..	..	0.51	2.83	12.86	1.97	0.99
Alumina (Al_2O_3)	..	..	1.33	3.10	1.37	1.25	1.41
Iron oxide (Fe_2O_3)	..	..	1.20	1.92	1.81		
Lime (CaO)	..	..	53.85	49.98	41.34	53.61	53.52
Magnesia (MgO)	..	..	0.40	1.21	1.59	0.63	1.06
Carbonic anhydride	..	..	41.40	39.08	30.80	42.40	42.32
Moisture and organic matter	..	..	1.07	1.47	8.42	0.46	0.66
			99.76	99.59	98.19	100.32	99.96

(1.) Limestone from Meek's Quarry, Teaneraki.

(2.) Hutchinson Quarry limestone, Oamaru.

(3.) Arenaceous Waitaki stone, Duntroon.

(4.) Calcareous Waitaki stone, Duntroon.

(5.) Limestone, Flat Top Hill, Kakanui.

ROCK PHOSPHATE.

Numerous samples of rocks from likely places were collected during the progress of the survey, with the view of determining their calcium-phosphate content. Samples were obtained at All Day Bay, Kakanui Quarry, road north of Rocky Peak, Deborah railway-cutting, Hutchinson's Quarry, Devil's Bridge, west branch of Landon Creek, Landon Creek, Big Flume Creek, and Borton's. The tricalcic-phosphate content was determined at the Otago University, with the following results:—

					Tricalcic Phosphate. Per Cent.
All Day Bay, base of greensands	..	..	..	..	2.13
Kakanui Quarry, top of limestone	..	..	..	..	1.79
Road north of Rocky Peak, top of tuffs	..	..	..	..	1.24
Deborah railway-cutting, top of conglomerate	..	..	..	..	2.46
Hutchinson's Quarry, top of conglomerate	..	..	..	..	2.12
Devil's Bridge, top of conglomerate	..	..	..	..	1.94
West branch of Landon Creek, base of greensands	..	..	..	..	2.41
Landon Creek, base of glauconitic sandstone	..	..	..	..	1.72
Big Flume Creek, base of glauconitic sandstone	..	..	..	..	1.54
Borton's, top of greensands	..	..	..	..	1.47

The average of three samples from the Hutchinson's Quarry limestone gave 0.72 per cent. of tricalcic phosphate.

There do not appear to be any rock-phosphate deposits of economic value in the Oamaru district.

APPENDIX.

1. NOMENCLATURE OF FOSSIL SPECIES.

WHILE this bulletin was in preparation and passing through the press a considerable number of alterations in generic and specific names were made on the authority of Mr. Suter. Unfortunately, it has been found impossible to embody all of them in the text. Many of the alterations were in manuscript species, descriptions of which are published in Palæontological Bulletin No. 5, which was in the press concurrently with this bulletin. The reader is requested to make the following corrections in the text of the preceding pages:—

For <i>Latirus acutiangulatus</i> Sut.	read <i>Tritonidea acutiangulata</i> Sut.
„ <i>Latirus compactus</i> Sut.	„ <i>Tritonidea compacta</i> Sut.
„ <i>Latirus elatior</i> Sut.	„ <i>Tritonidea elatior</i> Sut.
„ <i>Mangilia canaliculata</i> Sut.	„ <i>Bela canaliculata</i> Sut.
„ <i>Mangilia infelix</i> Sut.	„ <i>Bela infelix</i> Sut.
„ <i>Mangilia tenuilirata</i> Sut.	„ <i>Ptychatractus tenuilirata</i> Sut.
„ <i>Subemarginula intermedia</i> (Reeve)	„ <i>Tugalia intermedia</i> (Reeve).

The following new species from the Oamaru district, described by Suter in Palæontological Bulletin No. 5, may be added to those mentioned on the preceding pages:—

- Cantharidus fenestratus*. Calcareous tuffs, Trig. M, Oamaru.
Turbo approximatus. Locality No. 486, greensands, Wharekuri, Waitaki Valley.
Turritella (Zaria) abscisa. Oamaru. Exact locality unknown.
Sinum fornicatum. Right bank of Maerewhenua River.
Ficus parvus. Calcareous band in blue tuff below limestone, Rifle Butts, Oamaru.
Architectonica ngaparaensis. Locality No. 487, concretions overlying coal-beds, Ngapara.
Epitonium gracillimum. Left bank of Waitaki River, opposite Wharekuri.
Niso neozelanica. Left bank of Waitaki River, opposite Wharekuri.
Ptychatractus pukeuriensis. Pukeuri.
Vexillum fenestratum. Pukeuri.
Vexillum ligatum. Left bank of Waitaki River, opposite Wharekuri.
Euthria callimorpha. Left bank of Waitaki River, opposite Wharekuri.
Alectrion (Tritia) latecostata. Pukeuri.
Turris bimarginatus. Locality No. 630, Esdaile collection, Teaneraki (Enfield).
Turris neglectus. Locality No. 630, Esdaile collection, Teaneraki.
Mangilia blandiata. Trig. Z, Otiake River.
Borsonia mitromorphoides. Left bank of Waitaki River, opposite Wharekuri.
Daphnella (Raphitoma) neozelanica. Locality No. 630, Esdaile collection, Teaneraki.

2. CORALS AND POLYZOA (BRYOZOA).

Tenison-Woods* in 1880 described a number of corals and Polyzoa (Bryozoa) from the Oamaru district. The only one of these mentioned by name in the preceding pages

* Tenison-Woods, J. E.: "Corals and Bryozoa of the Neozoic Period in New Zealand." *Palæontology of New Zealand, Part IV*. Wellington, 1880.

is *Isis dactyla*. The species recorded by Tenison-Woods as occurring in the Oamaru district are,—

Corals.

Isis dactyla T.-Woods. Hutchinson's Quarry.

Notocyathus pedicellatus T.-Woods. Oamaru. Horizon not known.

Flabellum circulare T.-Woods. North bank of Maerewhenua River, from "Phorus beds overlying the Ototara limestone."

Flabellum(?) simplex T.-Woods. Limekiln Gully (*i.e.*, the gully below Hutchinson's limekiln, adjoining the quarry. (=Lower part of Target Gully.)

Flabellum radians T.-Woods. Oamaru limestone.

Flabellum attenuatum T.-Woods. Oamaru.

Flabellum sp., perhaps *F. laticostatum* T.-Woods. Oamaru.

Platyhelix distans T.-Woods. Awamoa beds, Oamaru.

Polyzoa (Bryozoa).

Spiroporina vertebralis Stol. Hutchinson's Quarry.

Eschara ampla T.-Woods. Hutchinson's Quarry.

Porina dieffenbachii Stol. Hutchinson's Quarry.

Celleporaria gambierensis Busk. Oamaru.

Celleporaria nummularia T.-Woods (*nomen nudum* of Busk). Hutchinson's Quarry.

Vincularia maorica Stol. Hutchinson's Quarry.

Cellaria punctata T.-Woods. Oamaru.

From Tenison-Woods's remarks it may be gathered that *Melicerita angustiloba* Busk, and probably other species of Polyzoa not mentioned above, also occur in the Oamaru district.

3. BRACHIOPODA.

Dr. J. Allan Thomson has kindly supplied the following brief diagnoses of new species mentioned in this bulletin. Fuller descriptions, accompanied by figures, will appear in a paleontological bulletin, of which the manuscript is now almost ready.

Genus *Hemithyris*.

Two valid species of *Hemithyris* have previously been described from the New Zealand area, *H. nigricans* (Sow.) and *H. squamosa* (Hutt.). The following new species also occur in the Oamaru district:—

H. antipoda: Type locality, Curiosity Shop, Rakaia River, Canterbury; dimensions of holotype—length 20 mm., breadth 22 mm., thickness 11 mm.

H. depressa: Type locality, limestone above tuffs, one mile north of Kakanui Quarry, Oamaru district (Uttley); dimensions of holotype—length 14 mm., breadth 16 mm., thickness 8 mm.

H. sublaevis: Type locality, Everett's limestone-quarry, Kakanui, Oamaru district; dimensions of holotype—length 10 mm., breadth 10.5 mm., thickness 7 mm.

H. nigricans, *H. squamosa*, and *H. antipoda* are about the same size, and are distinguished primarily by the character of the ribs. In *H. nigricans* these are stout, rounded, and not imbricate; in *H. antipoda* they are similar in size but rather more numerous, and are incipiently spinous; in *H. squamosa* they are finer and more numerous, and are incipiently spinous.

H. depressa and *H. sublaevis* are smaller species, both with short beaks. *H. depressa* is broader and more depressed, and possesses numerous fine ribs with imbrication towards the margin. *H. sublaevis* is more narrowly and strongly folded, and possesses numerous fine ribs, little imbricated, and in many specimens almost obsolete.

Genus *Liothyrella*.

Five valid species occur in the New Zealand area—viz., *L. grvida* (Suess), *L. concentrica* (Hutt.), *L. oamarutica* (Boehm), *L. neglecta* (Hutt.), and *L. magna* (Hamilton). The last species does not occur in the Oamaru district, and *L. neglecta* has not been identified with certainty, but probably occurs. The following new species are recorded in this bulletin:—

L. boehmi: Type locality, loc. 490, tuffs underlying limestone at Everett's Quarry, Kakanui (McKay, 1882); dimensions of holotype—length 52 mm., breadth 40 mm., thickness 32 mm.

L. pulchra: Type locality, calcareous tuffs. Trig. M, near Totara, Oamaru district (Uttley); dimensions of holotype—length 27 mm., breadth 24 mm., thickness 15 mm.

L. landonensis: Type locality, glauconitic limestone at the top of the Ototaran, Landon Creek, Oamaru district (Uttley); dimensions of holotype—length 16 mm., breadth 14 mm., thickness 8 mm.

L. boehmi agrees nearly in size with *L. grvida*, but is much narrower, and the condition of the foramen is less advanced, being marginate with only the beginning of labial projection.

L. pulchra is rather shorter than *L. oamarutica* and *L. concentrica*, and is relatively broader and more depressed. It is easily distinguished by being narrowly biplicate. The foramen is marginate in condition.

L. landonensis is slightly larger than *L. neglecta*, and is broader and more depressed. The foramen is marginate.

Genus *Pachymagas*.

Four species referable to *Pachymagas* have been named from New Zealand—viz., *P. triangularis* (Hutt.), *P. parki* (Hutt.), *P. marshalli* (Andrew), and *P. huttoni* Thomson. The first-named is known only from two specimens in the Dominion and Otago museums, each labelled "Oamaru" and with a greensand matrix, but the exact locality is uncertain. *P. marshalli*, although very different in shape from the holotype of *P. parki*, seems linked up to it by insensible gradations, and has here been treated as a synonym. *P. parki*, as here conceived, is therefore a polymorphic species, all the members of which are of similar size, and possess mesothyrid foramina of moderate size. Two new species have been differentiated, easily distinguished from *P. parki* by the size of the foramen, viz.:—

P. trelissickensis: Type locality, loc. 449, "lower beds, Trelissick Basin, Canterbury, Enys, 1880"; dimensions of holotype—length 40 mm., breadth 32 mm., thickness 20 mm.

P. ellipticus: Type locality, "greensands below the Maerewhenua limestone, Waitaki Valley" (Uttley); dimensions of holotype—length 29 mm., breadth 25 mm., thickness 14 mm.

P. trelissickensis in shape and size resembles the holotype of *P. parki*, but is less strongly folded, and is distinguished from similar variants of the *P. parki* series by the possession of a blunter beak with a large oval foramen, and of a slightly broader hinge-line.

P. ellipticus is a smaller species than *P. parki*, and is elliptical rather than ovate. It possesses a very short beak with a small foramen which is submesothyrid, but almost mesothyrid. The cardinalia are pachymagoid, with a primitive cardinal process.

Genus *Neothyris* (sensu lato).

N. esdailei sp. nov.: Type locality, loc. 831, tufaceous greensands, Upper Waiareka Valley, Oamaru district (Esdaile); dimensions of holotype—length 22 mm., breadth 17 mm., thickness 12 mm.

This is a ventrally biplicate species, agreeing in beak characters and folding with *Magellania johnstoniana* Tate, but less elongate than that species, and comparable in shape to half-grown specimens. The generic position is uncertain.

Genus *Terebratella*.

T. totaraensis sp. nov.: Type locality, calcareous tuffs, Trig. M, near Totara, Oamaru district; dimensions of holotype—length 10.5 mm., breadth 9 mm., thickness 6 mm.

This is a small, rather featureless, ovate species with occasional faint marginal multicostation in front. Young specimens agree nearly in shape with adults of *Terebratella oamarutica* Boehm, but are much narrower and more convex than young specimens of that species of the same length. In shape the species may therefore be described as similar to *T. oamarutica*, but more advanced in elongation.

~~Otago University, Dunedin, 10th June, 1916.~~



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